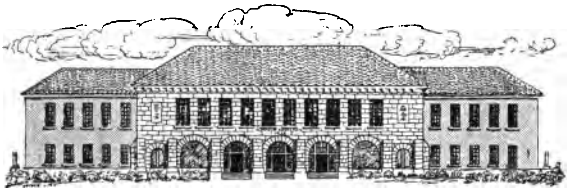
INTRODUCTION TO BOTANY

BERGEN AND CALDWELL



A CONIFEROUS FOREST OF SUGAR PINE AND FIR IN CALIFORNIA

INTRODUCTION TO BOTANY

BY

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GINN AND COMPANY
BOSTON · NEW YORK · CHICAGO · LONDON

514.2

The Athenæum Press
GINN AND COMPANY · PROPRIETORS · BOSTON · U.S.A.

PREFACE

This book treats the subject of botany from the same point of view that was adopted in the authors' "Practical Botany," but more briefly; that is, it endeavors to deal with the subject with constant reference to common educational, æsthetic, and practical interests in plant life. It also emphasizes the dynamic side of botany. The plant is not used primarily as a subject for dissection, nor for making a preserved specimen, but as an organism with a living to make—an organism that is forced to maintain its existence under conditions that are sometimes favorable and sometimes unfavorable to it. Constant effort has been made to render the style of the book simple and direct.

The object here sought is to present in a short course that kind of botanical knowledge which will especially interest the average secondary-school pupil, and which will be of most service to him as a means of education. Along with this training a good deal of other knowledge is presented, which should remain as a valued acquisition throughout the student's after life—knowledge of forest, field, wayside, farm, orchard, garden, and the industries. Since it has been shown that our disciplinary education may be useful in after life, mainly as the materials studied have elements in common with those later encountered, it becomes imperative that the elementary sciences should utilize in their content those things with which people are to come in contact. So much of the materials of botany is encountered by people in general throughout their lives that, according to recently accepted educational theories, this subject should have

peculiar educational significance. To this end those aspects of the plant world which touch human interests and activities ought to receive particular attention. It is essential, also, that the study be so shaped as to give the student a reasonable view of the phenomena of life as embodied in plants, for the average pupil (who does not go to college) will never again have so good an opportunity to learn about the simpler manifestations of life as is offered in his high-school course in botany. It is believed by the authors that every high-school pupil should be introduced to certain elementary and important facts regarding the life processes and problems of living things, and the first-hand study of plant life offers an especially favorable means of presenting these elementary biological truths.

The order of treatment here adopted is first to give a general notion of the world-wide distribution and importance of plants; then to enable the pupil to see the whole plant as a working machine; then to discuss more in detail the structure and work of the higher plants, each region of which performs a definite part of the work of the whole machine; then very briefly to present a general view of the great groups. Although throughout the book the plants used as the basis of study are usually those of common interest, a few of the most practical topics, such as timber and forestry, weeds, plant breeding, and the plant industries, are given separate treatment, with as much detail as is possible in a brief course. The structure, functions, and ecological relations of plants are presented throughout the book in a synthetic manner.

Questions pertaining to the interpretation and application of different features of plant life are introduced in the text and at the ends of chapters. Other similar questions raised by the teacher will be found helpful in presenting problems that the pupil should be able to solve in connection with his studies. Such problems help to develop the constant attitude of inquiry which science attempts to establish.

Valuable suggestions from many teachers and students of botany have been gladly received, and these will doubtless serve to render the book more helpful and usable than it otherwise would have been. Especial thanks are due to Dr. Norman MacLeod Harris of the Department of Bacteriology of The University of Chicago, who has read the chapter on bacteria; and to Mr. William L. Eikenberry of the University High School, Chicago, who by his frequent suggestions, based on extensive experience, has been constantly helpful in the preparation of this book.

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INTRODUCTION TO BOTANY

CHAPTER I

INTRODUCTORY

1. Interest in plants. All people are in some way interested in plants, although not every one recognizes that he has this interest. We all live largely on plants or plant products, and most of the world's workers earn their livelihood by some kind of industry which deals with plants or with their products. A glance at the food on any well-furnished table will suggest to what an extent our daily bill of fare consists of vegetable substances. Our animal foods — meat, milk, eggs, fish, and the rest — are only plant foods transformed more or less directly into animal tissues or animal secretions. Our spices and flavors and most of our medicines are plant substances or extracts. Part of our clothing is made from plant material. Our houses are often almost wholly constructed from timber, the furnishings are made from timber, and a home is scarcely complete without some growing plants, which assist in decorating the house and in giving pleasure to the occupants.

How raw materials derived from plants underlie most of the world's great industries cannot adequately be shown in a single paragraph. It is quite evident that the farmer, the gardener, the lumberman, the carpenter, the paper-maker, the cotton manufacturer, and the sail-maker are dealing with plants or with materials that are derived from them, but the multitudes of workers who make their living by sinking and operating oil wells, by refining petroleum, by mining and

marketing coal, or by any kind of manufacture in which the motive power is obtained by the aid of coal, oil, or gas used as fuel — all these people depend upon the products of the plant life that was abundant on the earth or in the seas during past ages. The air which we breathe is purified partly through processes by means of which green plants live. It is

FIG. 1. Sparse vegetation as seen upon the sand dunes along the shore of Lake Michigan

The wind-blown sand presents a poor living place for plants, although along the upper beach a fringe of trees and other plants has become established. In the view here shown the sand has been blown into definite ripples reaching down almost to the water of the lake

evident, then, that human life could not continue for a single week without the aid of substances produced by the life and growth of plants.

2. Plant production. The domesticated animals that are so extensively used to help man in his work, and those that he grows for food or for market, could not be cared for if it were not possible to have plants or plant products for their food.

If plant production were not so important to the world, there would be little need of having domesticated animals. Our

FIG. 2. Dense vegetation as seen in a tropical forest

During the relatively dry season, water may cease flowing in the stream bed here shown, but even then almost all available space is occupied by plants. During wet seasons in such regions plants often grow upon one another in quantities that break down the supporting stems

domesticated plants have been derived from wild ancestors. Many of these have been improved, until now their products are of much better quality or quantity than in their wild

condition. In the case of some of these domesticated plants — for example, wheat — it is possible that a single wild plant may have produced as much and as good wheat as one cultivated plant does now, but in most cases, doubtless, great improvements have been made, and in all cases the total product has been vastly increased. The northwestern United States produces wheat that is of great importance to the welfare of the nation. In the corn belt of the central United States there are seven states that produce nearly half the corn used in the whole world — an amount that is ordinarily worth annually almost three billion dollars. The cotton crop of the Southern states (three fifths of the cotton of the world), together with cotton-seed products, is worth annually nearly one billion dollars.

3. Plants are everywhere. Cultivated plants constitute only a very small part of the plant population of the earth. In fact, we are so accustomed to seeing plant life on every hand that we ordinarily think little about it. Most people have never been in surroundings where plant life is not fairly abundant. The upper parts of the cones of active volcanoes and the interiors of their craters, a few mud volcanoes and hot springs, the exposed surfaces of arctic ice fields or of glaciers, together with a few poisonous alkali tracts, are almost the only parts of the earth's surface on which or in which plant life is not present. There are, however, very great differences in the density of the plant population of different regions. Many deserts have only here and there a shrub or other plant capable of enduring the inhospitable soil and climatic conditions there encountered. In the sand hills which are found along the Great Lakes (fig. 1), along the shores of the Atlantic Ocean, and elsewhere few plants are able to grow. On the other hand, a weedy garden, a grass lawn, or a meadow usually has hundreds of plants to every square yard of surface, and tropical forests often present a tangled mass of vegetation (fig. 2) towering up to a height of nearly two hundred feet, interlaced with climbing plants, sometimes hundreds of feet

in length. Some very pure natural waters contain no plants readily visible to the eye, while the foul drainage of a barnyard in warm weather may be of a uniform bright-green color from the presence of many thousands of microscopic plants in every drop of the water. Plants occur in all the seas as well as in all the fresh waters, on every kind of soil from the wettest swamps to arid deserts, on rocky cliffs, and on branches and leaves of trees.

4. Structures and habits of plants. Although the relations of plants to human life and the life of the lower animals are of the highest importance, it is not this aspect of botany which is of largest concern to the beginner. We have no reason to suppose that plants exist for the benefit of man. Plant structures and processes are of importance primarily in maintaining the life of plants themselves, and their use by men is a by-product of plant life. In order to gain any scientific knowledge of elementary botany, it is necessary to try to find out what are the forms and internal structures of plants, how they carry on their life processes, and what relations exist between them and the external conditions of soil and climate. To these studies may be added some consideration of the relations between the plant and its plant and animal neighbors, and other studies about what plants have done for man and what he is trying to do with plants. But it must be clearly understood that the study of plant structures and functions — what plants are and how they live — is fundamental to any other study of plants.

CHAPTER II

THE PLANT AS A WORKING MACHINE[1]

5. The parts of the plant. Ordinary plants are composed of roots, stems, leaves, flowers, and seeds. Not infrequently some of these parts may be absent, or they may be so unusual in form and appearance that their nature is not readily seen. Thus, it is not usually evident to others than botanists (1) that an onion bulb consists of a very short stem and thick, broad leaves, and that when the onion grows, the roots descend from the lower part of the stem and green leaves and a flower-bearing stem arise from the upper end of the stem within the bulb; (2) or that in plants such as turnips and carrots the stem and root are not definitely set apart from one another; (3) or that the flowers of oak and elm trees, so very unlike flowers as we commonly think of them, have nevertheless as good a right to the name as has the flower of an apple tree.

The five parts of a common plant together constitute a well-organized unit (fig. 3). The parts differ from one another in structure, in form, and in what they do, but the successful work of each part contributes to the successful work of the whole plant. Although we may often be more interested in what is being done than in the mechanism which does the work, we cannot understand plant work except as we give constant attention to the structures of the parts of plants.

[1] This chapter gives an outline of plant structure and plant work. It does not present details, but gives a general idea of the nature and functions of the plant. If this outline is presented briefly, it serves to interpret the more detailed work of later chapters much more profitably than if numerous details are presented first. The chapter should be read carefully by every member of the class and discussed in one or two recitations, or it may be read and discussed by pupils and teacher together.

6. The work of plants. Plants must have materials for their nutrition just as truly as animals do. It does not follow, however, that the same kinds of food material are needed or that they are secured or handled in ways that correspond to those found among animals. As a rule, animals eat plants or animals that have used plants as food. Occasionally, as we shall see later, seed plants may use animals as food material, and it is generally known that such plants as bacteria and molds may live upon animals. Green plants may secure water and carbon dioxide, and from them they may make foods, such as sugar and starch. They may use these as food or may combine them with other substances and thus make foods, such as proteins, that are more complex than sugar and starch. It is also one of the conspicuous and important facts of plant life that much surplus plant food is stored in grains and fruits, and this stored food may serve as nutrient material for man and the lower animals. Indeed, many people find that their chief interest in plant life is due to the possibility of securing and using this surplus stored plant food as found in such things as the grains

FIG. 3. An indian-corn plant with roots, stem, leaves, and flowers

Two kinds of flowers are formed, one in the ear (*e*), from which the silk (*s*) protrudes, and the other in the tassel at the tip of the plant. Special brace roots (*b.r*) are sometimes formed

of corn, wheat, and oats, in the vegetables and fruits, and in the oil of corn and cotton. It must also be noted that many tissues or fibers of great significance — such as cotton,

FIG. 4. A red-oak tree whose roots have lost their anchorage through removal of the soil by water

Compare the position of the tree with that of the beech and other trees in the background

hemp, flax, and the timbers of commerce — are produced in connection with the ordinary processes by means of which plants manufacture plant foods and use them in their growth.

7. Roots. In places such as very steep hillsides or along river banks one may often see plants whose roots have been uncovered by removal of the soil in which they grew. When the soil is removed, the roots sooner or later are unable to hold the rest of the plant in place, and it may fall to the ground (fig. 4). When their roots are partially uncovered, trees that have withstood heavy winds for years may succumb to winds that are less severe than many which they had previously been able to withstand. In cultivated hilly fields heavy rains often erode the soil from above the roots to an extent that allows the plants to fall. Obviously one function served by roots is that of holding plants in place; this is called *anchorage.*

But oftentimes one may observe plants whose roots are partially uncovered, the plant still erect in position but wilting or with yellow leaves and evidently not growing well. Furthermore, in some cases the roots on one side have been uncovered and the plant has fallen, but its branches and leaves are still in a thrifty condition. If all or nearly all the roots are exposed, or if the soil is extremely dry, the water supply of the plant, which comes through the roots, is interfered with, and because of a shortage of water the leaves may wilt; but if a part of the roots are still well imbedded in moist soil, though the stem and branches may have fallen, a fairly adequate supply of water may still reach the stem and leaves, and wilting and death may not follow. Roots, therefore, serve not only for anchorage but also as structures through which the plant receives its water supply, that is, as organs of *water absorption.*

8. Rootlets and root hairs. In examining the root system of any common plant (fig. 3) it is usually seen that the roots directly joined to the stem are relatively few and large, and that they divide and redivide until extremely fine rootlets are formed. In most plants the larger roots are covered by bark, through which water does not pass readily. Even rather small root branches are covered with root bark. But the smallest

and terminal rootlets have no bark, and from their surfaces there grow very fine tubular threads known as *root hairs* (figs. 5 and 6). Root hairs have extremely thin walls, through which water from the soil can pass into the interior; thence it passes upward through rootlets and larger roots, through the stem and into the leaves. Substances that are in solution in the soil water may be transferred into the plant through the delicate walls of the root hairs and their lining. Root hairs do not grow over all the surface of the terminal rootlets, but develop a little way from the root tip. They do not live very long, the older ones constantly dying. Thus, as the root tip grows forward through the soil the actual number of root hairs on a rootlet may remain practically constant during the growing season, on account of the dying of older root hairs and the development of new ones near the root tip on the new growth of the rootlet. It is evident that the area of root hairs advances, although no individual root hairs move forward through the soil. Although extremely delicate in structure, root hairs grow between and around the hard particles of soil (fig. 6). It is easy to count the root hairs on a small portion of the root. Corn rootlets grown in damp air have been found to bear 425 root hairs on an area $\frac{1}{25}$ inch square. The large number of rootlets and the enormous number of root hairs serve to make a network which completely permeates the soil in the region of the rootlets. The root hairs are the chief organs by which water and substances in solution in water are absorbed from the soil.

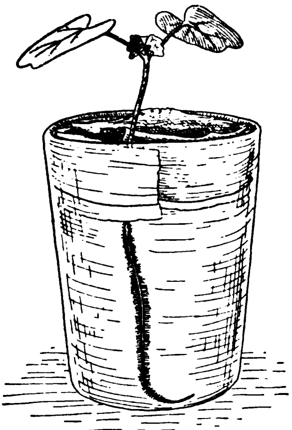


FIG. 5. A mustard seedling grown in a band of filter paper inside a drinking glass, so as to show the root hairs

Note the difference in length and condition of the root hairs on the different parts of the root

9. Stems as supporting structures. In an examination of the stem of almost any woody plant there appears an outer dead bark, an inner green bark, a cylinder of wood, and sometimes a small area of pith in the center of the woody cylinder. Although some of our commonest agricultural plants, as corn and wheat, do not have a central woody cylinder, they have an outer region of very hard, strong tissue, and either a hollow central region, as in the wheat, or a large pithy center through which run a number of fibrous bundles, as in corn (fig. 7). In wheat the fibrous bundles lie close to the hard outer portion of the stem; consequently they are not seen nearly so easily as are the fibrous bundles in corn. A stem could not stand alone in an upright position if it did not possess some such rigid tissues as those generally noted in woody plants or in the outer portions of corn and wheat stems. Other factors that help in maintaining an upright position of the

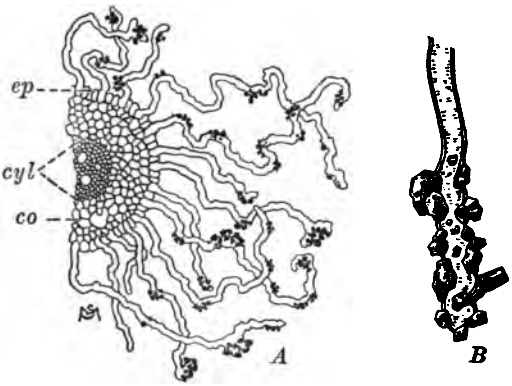


FIG. 6. Root hairs

A, a cross section of a root, showing the central cylinder (*cyl*), the cortex (*co*), and the epidermis (*ep*), with root hairs that have grown from epidermal cells. *B*, a root hair enlarged to show the soil particles attached to it

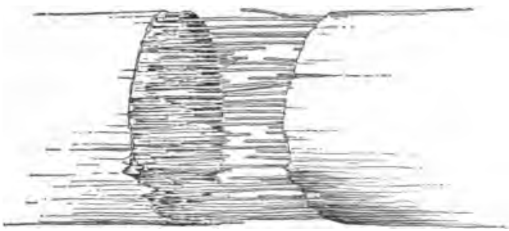


FIG. 7. A cornstalk broken so as to show the number and distribution of the vascular bundles

stem will be discussed in later chapters. By means of their upright position, stems may support the branches and leaves in such a way that they are upheld in the air. *Support* is evidently one of the conspicuous functions served by plant stems.

Many plants live for only one year (*annuals*) or two years (*biennials*); in such plants large and strong stems are not often found. Other kinds of plants may live for two or more years (*perennials*). Woody perennials may live for hundreds of years, and their stems usually increase in thickness from year to year, until, in the case of trees, stems are sometimes developed which are several feet in thickness, much over a hundred feet in height, and of such strength that very heavy tops are upheld throughout the severest storms. The increase in thickness is shown by the *annual rings* of wood (fig. 8). Often the age of a woody stem may be indicated approximately by its annual rings, but that these are not always truly annual rings is shown by the fact that when there are intermittent favorable and unfavorable growing periods within the same season, more than one ring may be formed within one year. Cases are known of young trees that have almost twice as many rings as the number of years of their age.

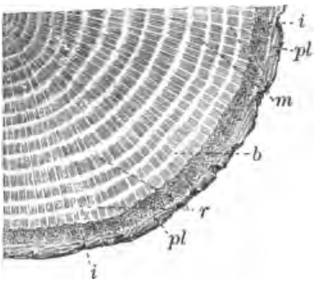


FIG. 8. One quarter of a cross section of a stick of oak wood

m, medullary rays, running from bark to pith; *r*, annual rings; *b*, boundaries between rings, porous from presence of many ducts; *i*, interior fibrous layers of dead bark; *pl*, hard plates of dead bark, splitting away from each other but attached to bark beneath. Reduced

10. Stems as passageways for liquids. When the stem of an actively growing plant is cut, water sometimes exudes upon the cut surface of the stump. The same outpouring of water is seen when a leaf of a corn plant is peeled away from the stalk. When we wish to keep cut flowers in a fresh condition, we place their stems in water. If we should place a fresh leaf of celery in a solution of one of the aniline dyes

and let it remain for a few minutes, and then remove it and examine it by sectioning, definitely stained regions would be seen, other regions being unstained, thus showing not only that the liquid passed upward through the leafstalk, but that it passed through certain tissues of the stalk. If a leafstalk of celery is carefully broken and one part pulled slowly away from the other, there are seen fibers, or threads, which are quite like those shown in the cornstalk (fig. 7). These threads are known as *fibrovascular bundles*, which means simply "collections of thread-like tubes." It is through these fibrovascular bundles that water and substances in solution in water pass from the soil through roots, through stems, and into leaves. Through them also plant foods may pass from leaves downward through the plant. Indeed, there are certain parts of each bundle through which water passes upward, and other parts through which the organized plant foods are carried. The fibrovascular bundles, therefore, are the chief transportation lines of the plant.

11. Leaves. Most leaves are expanded so that they expose much more surface than would stems of equal weight. In some cases (fig. 3) the entire leaf is expanded, while in others there is a leafstalk, or *petiole*, and the expanded portion, the *blade*. The leaf blade may be single (*simple*) or sub-divided (*compound*). From the plant stem the fibrovascular bundles extend into the leaf, where they are known as the *veins* of the leaf. They terminate in the leaf, sometimes in its tip and sometimes in the margin as well as in the tip. Water from the soil may therefore pass through the fibrovascular bundles of the roots, the stem, and the leaves, into the interior of the leaf. From the leaf some of this water is evaporated into the air.

Part of the water in the leaf, instead of being evaporated into the air, is used in the construction of plant food by means of a process which is of very great importance to all living things. Carbon dioxide from the air enters the leaf through its surface. The leaf is green because of the presence of a

coloring substance known as *chlorophyll.* When the sun shines upon the leaf, the chlorophyll absorbs energy from the sun's rays. This energy serves to decompose the water and carbon dioxide. The products of this decomposition immediately reunite, but into new substances, which, after several chemical changes, may become sugar or starch. Sugar and starch may be used as food by the leaf, or be carried to other parts of the plant and used, or be made into more complex foods, as oils or protein foods. It is from foods that plants as well as animals derive the energy that makes activity, growth, and life itself possible.

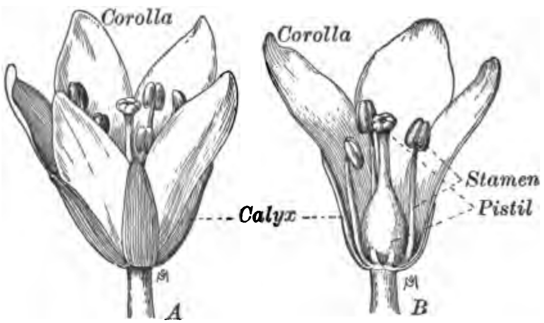


FIG. 9. Diagrams of two flowers

A, entire flower; *B*, flower with part of the floral structures removed

Since water and carbon dioxide, the substances from which a green plant thus manufactures food, are substances that are not ordinarily regarded as foods for other living things, this process is far-reaching in its significance. The storage of surplus plant food in seeds (fig. 12), roots, stems, and leaves is also most significant, since our food and many of our industries depend upon this surplus material.

12. The flower. In addition to the roots, stems, and leaves, flowers are often conspicuous parts of plants. They are the structures by means of which seeds are produced. In some plants but one kind of flower is produced (fig. 9); in others two kinds are formed (figs. 10 and 11). In such a flower as that shown in figure 9 the outermost and lowest floral parts form the *calyx*, each part being a *sepal;* the parts next above the calyx constitute the *corolla*, each part being a *petal;* above

the corolla are the *stamens;* and at the center of the flower is the *pistil.* Within the enlarged stamen tip, or *anther*, are many grains of *pollen*, and within the swollen basal part of the pistil (the *ovary*) are one or more *ovules.* The ovules are the developing seeds.

In such plants as indian corn and other members of the grass family, to which corn belongs, *staminate* (stamen-bearing) flowers are often found on one part of the plant and

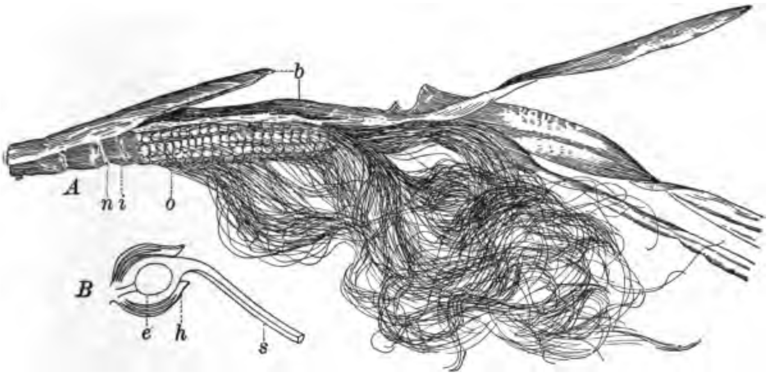


FIG. 10. A young ear of sweet corn

A, entire ear, showing the joints, or nodes (*n*), and the internodes (*i*) of the branch which bears the ear; the leaf-like bracts (*b*) which inclose the ear, and the grain, or ovary (*o*), to each of which one of the silks is attached. *B*, an enlarged diagram of one grain, showing the embryo sac (*e*), the inclosing husk, or chaff (*h*), and the silk (*s*)

pistillate (pistil-bearing) flowers on another part (figs. 10 and 11). In corn the staminate flowers are known collectively as the tassel, and the pistillate flowers collectively as the ear. Each staminate flower consists of a simple leaf-like bract which incloses three stamens. The amount of pollen borne by a single tassel is very great; it is estimated by one authority[1] that from 20,000,000 to 50,000,000 pollen grains have been borne by a single corn plant. A single pistillate flower consists of a short and obscure *bract* (often called

[1] DeVries, Plant Breeding. The Open Court Publishing Company, 1907.

chaff) and an ovule with an elongated *style* (called *silk* in corn), which grows attached to the ovule's tip. The tip of the style, or silk, is the *stigma*, which is the roughened, sticky surface to which pollen grains may adhere when they fall upon it.

13. The seed. From a pollen grain which has fallen on the stigma there grows downward through the style a very small

FIG. 11. Two branches from the tassel bearing staminate flowers

tube (the pollen tube), which finally reaches the interior of the ovule, where there is a very small egg. This egg is fertilized by its union with a smaller body carried by the pollen tube, and from the result of this fertilization a new embryo corn plant develops within the ovule. While still within the developing ovule, or seed, this young plant produces its root tip and stem tip; in corn and other grass seeds there is a special structure (scutellum) by means of which the embryo

plant absorbs food material from the ovule. While the embryo plant is developing, food material is constantly being transported into the grain, or ovule, until finally a relatively large amount of food material is thus deposited (fig. 12). The ripened seed, or grain, consists of the old ovule wall, the stored food material, and the embryo corn plant. The scale-like bract, or chaff, which surrounded the young ovule, often adheres to the ripened grain. In many kinds of plants

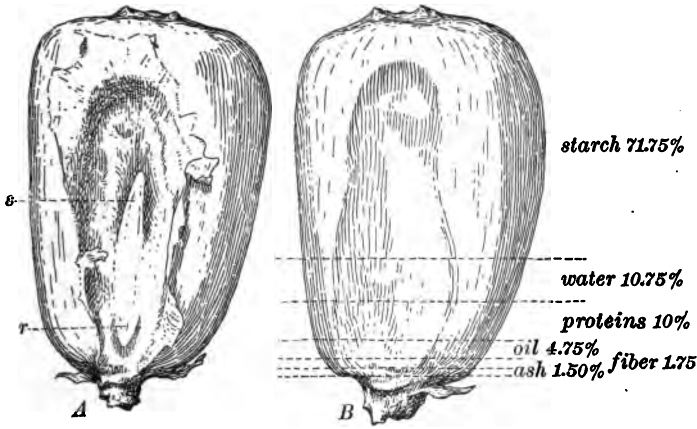


FIG. 12. Grains of indian corn

A, a grain with seed-covering partly torn away, showing the root tip (*r*) and the stem tip (*s*) of the embryo corn plant within the seed. *B*, a grain showing the percentage of different substances that compose it

the ripened seed or seeds may be surrounded by one or more structures, the whole then composing the so-called fruit.

14. Seed germination. Seeds may lie dormant for a very long time or may grow soon after being formed. Under favorable conditions the young plant within the seed bursts the seed coat and continues its growth as a new plant. It pushes out its root, stem, and leaves and soon assumes the appearance of the kind of plant that formed it (figs. 13 and 14). In some kinds of plants, when the seed germinates, the seed coat remains underground and the stem and leaves grow

upward from it; in others the seed coat is carried upon the seed leaves until they appear above the surface of the ground, when by the spreading of the seed leaves the coat is dropped (fig. 13). Some kinds of plants have one seed leaf, as in corn; while others, as the sunflower, have two seed leaves, between which the first true leaves appear.

15. Further study of the parts of a plant. It must be evident from the discussion in this chapter that a plant is

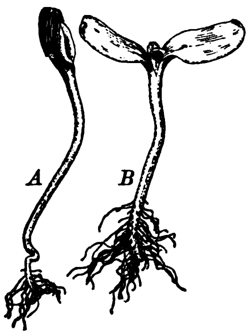


FIG. 13. Seedlings of the sunflower plant

A, old seed coat still partly inclosing the seed leaves; *B*, seed leaves open and first true leaves appearing

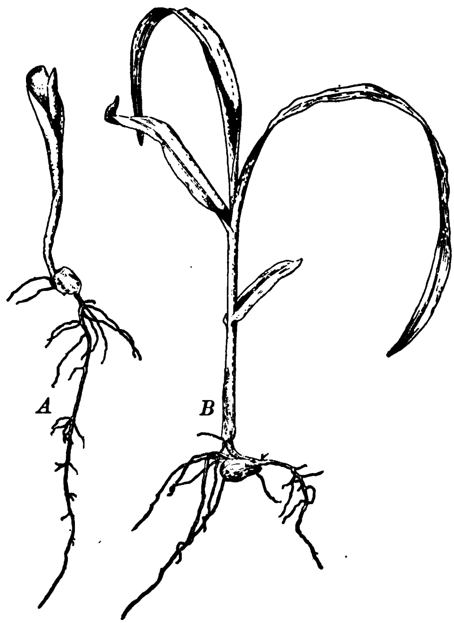


FIG. 14. Young corn plants

A, leaves unfolding; *B*, leaves and other parts well developed

a sort of machine consisting of roots, stem, leaves, flowers, and seeds. By means of this plant machine raw materials are secured and manufactured into plant food. This manufactured food is distributed through the plant; some of it is used immediately and some of it is stored. Seeds are manufactured, and by means of them new plants are started on their round of activities. Having in this chapter merely outlined the nature of the plant machine and the work done by

it, we must now consider in greater detail the special features of each part as these are shown by more careful study of their structures and work. Succeeding chapters will deal with these matters, but to see clearly the significance of special structures and functions this unit outline of the whole plant and its work should be kept constantly in mind. The student can come to an understanding of the life of the plant only by observing how its organs coöperate in the processes of nutrition, growth, and reproduction. It has been the purpose of this chapter to give an outline of the whole plant; to raise questions concerning what a plant is and how it works; and to suggest, in a general way, the answers to these questions. Such a general view of the nature of a plant furnishes the best basis for further study.

CHAPTER III

ROOTS AND THEIR RELATION TO THE WORK OF PLANTS

16. Structure of roots. We have already discussed the general nature of roots. Careful examination of a cross section of a young root shows that there is a definitely organized *central cylinder*, around which is the *cortex*, both well shown in figure 15. The surface layer of the cortex is the *epidermis* (fig. 16, *e*). The growing root tip is covered with several layers of dead or dying cells, which make up the *rootcap*. As the root pushes its way through the soil the rootcap is constantly being worn away on the outside. During the seasons of activity the rootcap is continually being rebuilt by the formation of new layers of cells on its inner surface. In older roots the epidermis has given place to *bark*, which is composed of several layers of cells. If a cross section of a very young root of a dicotyledonous plant is examined with a moderate magnification, it will be seen that the cortex is made up of rather loosely aggregated cells, while the central cylinder is more closely compacted. In the cylinder are found a definite number of radially arranged fibrovascular bundles. The woody strands of these bundles alternate with strands of what are known as *bast fibers*, shown in figure 44.

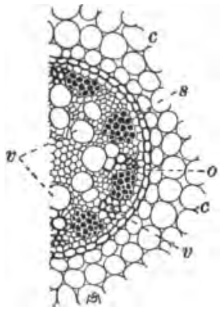


FIG. 15. Cross section of central portion of root of sweet flag (*Acorus*)

c, cortex; *o*, outermost layer of cells of central cylinder; *v*, vessels of various sizes; *s*, sieve cells. Magnified 70 diameters. After De Bary

17. The root-hair cell. The general tubular structure of root hairs was very briefly explained in section 8. A root hair,

together with the minute sub-division of the epidermis from which it springs (fig. 16, *e*), furnishes a good example of one kind of plant cell.[1] Each live root hair consists of an extremely thin sac, the *cell wall* (shown in figs. 6 and 16 merely as a continuous line bounding the root hairs), and the living contents of the cell, known as the *protoplast.* The cell wall consists of a material known as *cellulose,* familiar to all in the microscopic fibers of cotton. The cell contents, or protoplast, of a root hair consists largely of a nearly transparent portion, the *cytoplasm,* composed of nitrogenous material which may be roughly compared to very thin white of egg. Within the cytoplasm are found many somewhat opaque and very minute particles, also rather large, clear spaces consisting of very watery cell sap, and a structure less transparent than the cytoplasm, known as the *nucleus* (fig. 16, *n*).

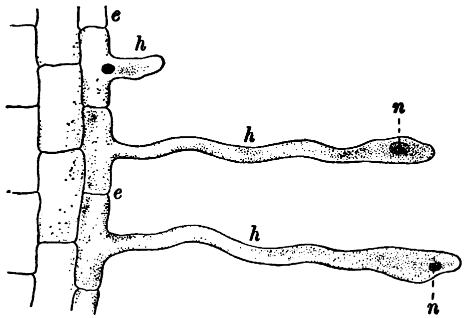


FIG. 16. Cells from the surface of a young rootlet

Showing epidermal cells (*e*) and one young and two older root hairs (*h*). In the root hairs the nucleus (*n*) and granular cytoplasm of the cells are shown. Greatly magnified. After Bonnier and Sablon

Other cells, of more complicated constitution than root hairs, often contain many other structures and materials besides those here mentioned. Some of these are briefly discussed and figured in Chapter IV.

18. The work of cells. The simplest plants, as will be shown later, consist of a single cell each. Every ordinary flowering

[1] The student will find many illustrations of different types of cells in later chapters. Some very simple ones are discussed in Chapter XV. Many cells of the lower forms of plant life are much more easily studied than the colorless and nearly transparent root hairs. The minute anatomy of the cell is most easily studied in cells which exist as separate individuals and which have among their contents some colored structures.

plant consists of hundreds of thousands or millions of coöperating cells, which together carry on the work of the plant.

The root-hair cell shows its life most clearly by growing and making its way around obstacles (fig. 6). Other plant cells often give much more striking evidence of life in the movements which are executed by single cells or by organs built up of great numbers of cells. Many such movements will be described in subsequent chapters. In this place it is sufficient to call the student's attention to the fact that the protoplast is alive in just the same sense that any minute animal is alive. Whatever any living organism can do it does by virtue of the energy of its protoplasts.

The most remarkable and peculiar of the characteristics of protoplasm are due to its possessing *irritability*. By this is meant the power to respond in some definite way to any suitable *stimulus*, or exciting cause, acting from within or without the plant body. Some of the principal stimuli are gravity, heat, light, chemical substances, and contact with solid objects. When protoplasts, either singly or combined into some organ of the plant, are acted upon by any stimulus to which they are sensitive, there is usually no immediate visible response. If, for example, a young seedling with a stout taproot is pinned horizontally to a piece of cork which lines the vertical side of a glass jar containing moist air, no change is at first noticed. In a few hours, however, the part of the root for a short distance back of the tip will be found bending vertically downward. This movement is a response to the stimulus of gravity, acting upon the very sensitive young root and causing unequal growth in the upper and lower sides. It is not a mere bending, like that of an unsupported piece of wet string, for the moving end-portion of the root will be found to push downward with a force of more than ten times its own weight.

19. Turgidity. Root hairs and other cells of plants usually take up water until the cell walls are distended with water and protoplasm. The outward pressure which distends and stretches the walls is called *turgor*, and the resulting condition

is called *turgidity*. Turgor doubtless helps to force water upward through the stem. The distention of cells due to turgor also accounts for the rigid or erect position of most leaves, growing shoots, and succulent stems. Each distended cell, like an inflated balloon, assumes a semi-rigid position, and a mass of distended cells pressing against one another makes the whole

Fig. 17. A young cucumber plant (grown in a flowerpot)

At left, in normal condition; at right, much wilted from having been left unwatered for several days

structure rigid. But just as, when the air escapes from a balloon, its wall collapses of its own weight, so the cells of the leaves and shoots collapse when, on account of loss of water, they lose their turgidity. When soil water is not available to the plant, the outgo from the leaves is often greater than the income from the roots, and in such cases wilting follows (fig. 17). If water does not again become available, the plant will die, but with a renewed supply turgidity and the resulting rigidity soon return.

20. Amount of water pressure in woody plants. When very little water is being lost by evaporation from the leaves, the sap pressure in trees and large shrubs is often great. As a result of this pressure, in early spring sap escapes freely from cuts or borings made into the roots, trunks, or branches of many kinds of trees and shrubs. The "bleeding" of grapevines pruned too late in the season is familiar to many people, as is also the flow of sap from sugar maples. Woody plants cut off near the root may have a pressure gauge of any convenient sort attached to the cut surface, and the pressure can thus be measured with accuracy. A severed grapevine has been found to exert a pressure sufficient to sustain a column of water more than 43 feet high, and the root of a black birch tree a pressure equivalent to about 86 feet of water.

In the tallest trees, the giant redwoods and the Australian gum trees (*Sequoia*, *Eucalyptus*), water is sometimes raised to a height of from 300 to 400 feet. It is not yet known how large a part of the force required for this is due to the pressure with which the sap from the roots is impelled up into the stem, nor what other causes are mainly responsible for the rise of water into the highest portions of the tree.

21. What roots do for the plant. All plants must have water, at any rate during the part of their lives when they are actively manufacturing plant food, and it is by means of their roots that most familiar plants absorb water and the substances that are dissolved in it. Yet absorption of water is not the only function of roots. They often absorb oxygen; they commonly serve to anchor the plant; they may aid it to climb; they frequently store food, water, or both; and in or on them are sometimes carried on important chemical operations which result in gaining material for the production of plant food. Many kinds of roots reproduce the plant; that is, a root or part of one may grow into a new individual plant like the one to which the root belonged.

The great importance of roots to life and growth is well shown by the results which follow from any severe injury to

the root system. Cut off most of the roots of a tree and it will die for lack of water. On the other hand, many (though not all) kinds of trees may be cut down nearly level with the ground and still survive, the stump throwing up a vigorous crop of sprouts, which grow into saplings that eventually replace the fallen trunk.

The necessity of roots for anchorage is well shown by figure 4. In many cases the power of the roots to hold trees upright is greatly increased by the formation of buttresses of wood, which extend for some distance up the trunk from the origins of the larger roots. In some large tropical trees these buttresses attain enormous dimensions.

22. Earth roots; direction and extent of root system. The roots of most common flowering plants in temperate regions are *earth roots;* that is, they grow in and through the soil. The nature of the soil greatly influences the extent and position of the root system. Sandy soils favor the development of an extensive root system, while clay soils do not. If the good soil forms only a shallow layer over shale or sterile clay (or in the arctic regions over ice), the roots spread out in a flat, mat-like fashion.

The smaller rootlets are so woven through the soil that it is never possible to unravel the entire root system. The roots of a single oat plant, if arranged in a straight line, have been found to measure over 450 feet in length. Desert shrubs sometimes send their roots down as much as 60 feet toward the water supply. In parts of California it has been found that common farm plants, such as alfalfa and wheat, may have roots reaching moist earth at a depth of from 13 to 15 feet.

Why is deep plowing between hills of half-grown corn likely to injure the crop?

23. Pull of roots due to shortening. Frequently rootlets or the taproots of herbaceous plants shorten after they are fully grown. This shortening has a tendency to pull the stem and leaves of the plant downward. It is interesting to notice how some plants with rosettes of leaves, like chicory, dandelion,

and fall dandelion, pull their rosettes down tightly against the surface of a lawn, kill the surrounding grass, and thus secure for themselves a little clear space in which to grow.

24. Effects of roots on the soil. If we dig up a spadeful of earth from a well-grassed meadow or from a little inside the circumference of the circle formed by the roots of a tree, we shall find the soil bound together by the living roots or full

FIG. 18. Cypress trees (*Taxodium*) growing in a swamp

The conical "knees" growing from the roots and nearly always above water are thought to serve as channels to supply air to the roots

of little, crooked, tubular channels left by the decay of dead ones. Thus the soil is in the one case held together so as to prevent its becoming gullied and washed away by rains, and in the other case made more porous and more easily penetrated by air and water. The latter effect is a very important one in the case of stiff clay soils, which, when closely packed, are almost waterproof.

The extensive washing away of soils when they are unprotected by a covering of plants, such as grass, shrubs, or forest

growth, is one of the most serious calamities that can befall a country. It is especially formidable in hilly regions, which may become wholly uninhabitable if the forests are cut off and the turf on the hillsides is destroyed by too constant grazing and trampling of sheep or goats. Throughout southern Europe immense areas of land once valuable for timber and for grazing have thus been ruined, and the same process is under way in our own country all the way from New England to the Pacific coast region. One of the clearest ways in which the idea of loss by the washing away of the soil can be presented is by considering how the land is carried into the sea by great rivers. The delta of the Mississippi covers an area of more than 12,000 square miles. It consists of material brought down by the river in the form of mud, which now forms a deposit of unknown thickness, probably averaging more than 500 feet. It is calculated that the river carries every year enough solid matter to form a layer one foot thick over an area of about 268 square miles. Remembering that this mud consists mainly of the choicest part of the rich soil of the Mississippi basin, it is easy to see that the land is robbed every year of the material to support enormous harvests[1] (see Chapter XIX).

25. Air supply of earth roots. Earth roots require a considerable supply of air. This is shown by the fact that most trees are injured or killed when the soil in which they grow is long flooded with water, as is often the case when a stream is greatly widened by the construction of a dam across it. The same result is seen when low fields of corn, wheat, oats, or cotton are flooded after heavy rains. Unglazed earthen flowerpots are better for house plants than glazed ones or glass jars, because they allow air to pass freely through the porous material of the pot.

How do the earth roots of such plants as water lilies get their air supply?

[1] See "Forest Influences," *Bulletin No. 7*, Division of Forestry, U.S. Dept. Agr., 1893.

Sandy soils contain more abundant air spaces than compact clays, and in clayey regions one important reason for deep and thorough cultivation of the soil is to insure the free access of air to the roots of crops.

FIG. 19. Effect of deficient water supply on growth

The plant is groundsel, a common European weed which grows to from 12 to 18 inches high. At *D* is shown the relative height of the same plant when grown in very dry sands along Mediterranean beaches. Modified after "Flora Danica"

26. Water supply of earth roots. It is known to most people that ordinary plants must absorb through their roots a good deal of water. If house plants are left unwatered for two or three days, they begin to wilt. Field crops and sometimes even shade trees do the same in times of severe drought. Many plants, when grown in dry ground, will flower and seed in a dwarfed condition. The common groundsel, a weed not infrequently found in long-tilled fields and about dooryards (fig. 19), under favorable conditions grows to be a foot or more in height, but in the very dry sand along Mediterranean beaches this plant flowers and seeds when only an inch high.

27. Roots of desert plants. The plants of desert and other dry regions frequently show striking peculiarities of form and structure, and among these is an unusual development of the root system. Plants able to live under extremely dry conditions are known as *xerophytes.* Familiar examples of these are century plants and cacti. Some xerophytes, as the cacti, have a rather widely spreading root system extending quite near the surface of the earth ; such a root system makes the most of every one of the infrequent

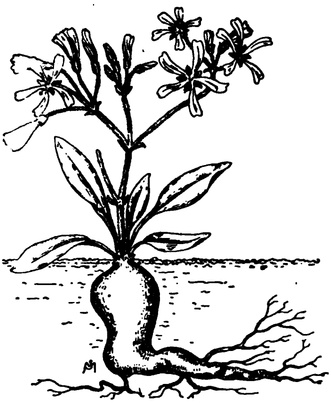


FIG. 20. A desert *Pelargonium* (closely related to the common so-called geraniums)

Note the scanty leaf surface and the fleshy root and base of the stem, containing much water and reserve food. After Andrews

rainfalls of the regions where these plants grow. Others, as the mesquite of the extreme southwest, have roots that penetrate into the earth to extraordinary depths until they reach moist soil. Still others — for example, many South African plants (fig. 20), some wild morning-glories, and the bigroot[1] of the Pacific coast — have fleshy roots in which much water is stored.

28. Water roots. Most aquatic perennials, like the cat-tails, arrowheads, pickerel weeds, pond lilies, and many grasses and sedges, form mainly earth roots. On the other hand, some plants not aquatics — for example, many willows — can develop roots indifferently either in earth or in water. Willows growing along a brook usually send great numbers of roots into the earth, and also produce a multitude of fibrous roots which dangle in the water. Cuttings of Wandering Jew (*Zebrina*), geranium (*Pelargonium*), and many

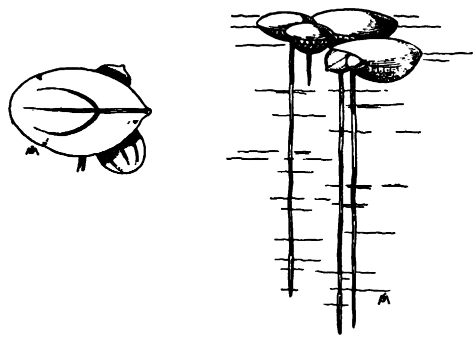


FIG. 21. Duckweed, a floating aquatic plant

At left, top view of single plant 8 times natural size; at right, group of three individuals of another species represented as floating, with roots hanging vertically. Three and one-half times natural size. After Prantl

[1] *Echinocystis.*

other common plants root readily in water and grow for a long time if supplied only with ordinary river or well water. The number of kinds of seed plants which float, and therefore

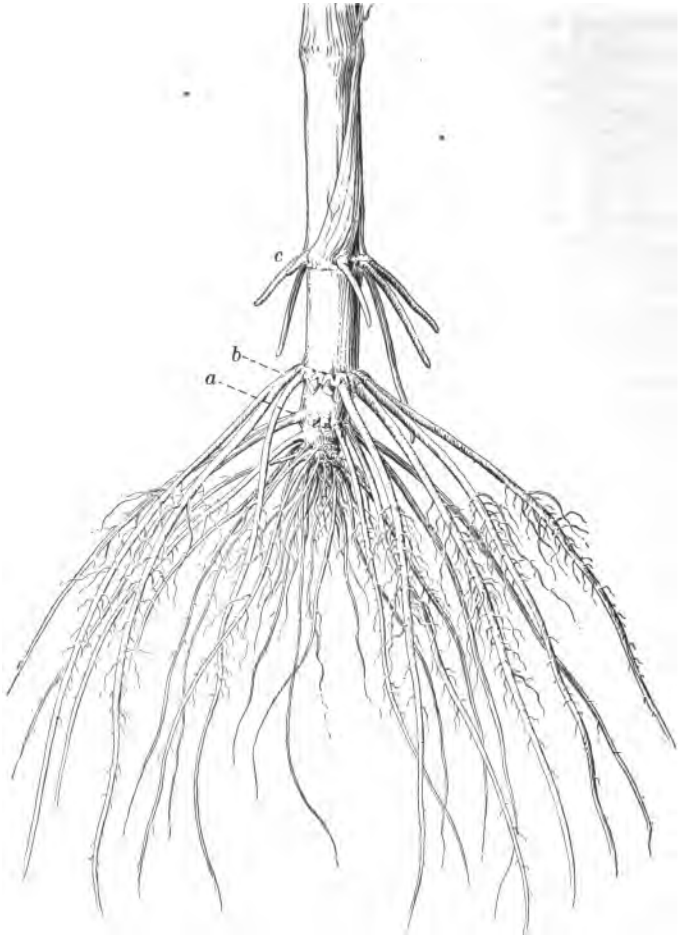


FIG. 22. Aërial roots (brace roots) of corn. Reduced

Note that the series *a* and *b* began as aërial roots, but later entered the ground and then developed many small branches. Those at *c*, if not checked by frost, would eventually also have reached the ground

produce only water roots (if they have roots at all), is rather small. Some of the commonest are the so-called water hyacinth and the little duckweeds (fig. 21).

Plants like the pondweeds, water crowfoot, water weed (*Elodea*), and others, which grow entirely submerged, do not need an extensive root system, as they are in no danger of drying and so use their roots mainly for anchorage.

29. Air roots. Many plants which root in the earth, such as corn, poison ivy, and English ivy, produce roots from portions of the stem aboveground. These are called *aërial* roots. In some cases, as in corn (fig. 22) and in the mangrove tree, which grows along tropical coasts, the aërial roots finally reach the earth and serve as braces to prop the stem of the plant upright. In other instances the roots never reach the ground, and then they may serve to enable the plant to climb, as in the case of the poison ivy and the English ivy, or they may serve to anchor the plant to stones or to the bark of trees and at the same time to absorb rain water or dew. Many tropical *air plants* are perched on the bark of trees, or even on their leaves, and get their water supply from dangling aërial roots which are covered with a layer of absorbent bark that catches water and then gradually gives it to the plant.

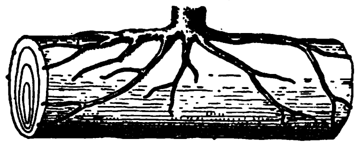


FIG. 23. Base of stem and sucking roots of the mistletoe, growing on an apple branch

In the figure the bark of the branch has been removed so as to show how the mistletoe roots spread between the bark and the wood of the host plant. In the section of the branch at the left is shown the way in which short portions of the mistletoe root penetrate into the wood of the host. One half natural size. After Bonnier and Sablon

30. Parasitic roots. Certain plants, such as the dodders (fig. 34) and many kinds of mistletoe (figs. 23 and 35), live wholly or partly at the expense of other plants, into which their sucking roots, or *haustoria*, penetrate, sometimes very deeply. The mode of life of such parasites will be further discussed in Chapter IV.

31. Reproduction by means of roots. Roots are often capable of producing buds which may develop into new individuals and thus propagate the plant. The sweet potato is a good instance of this, each root, if buried in moist sand, being capable of giving rise to several new plants (fig. 24). Roses are propagated by root cuttings, and some trees, such as the silver-leaved poplar (*Populus*) and the black locust (*Robinia*), are very troublesome because of the readiness with which young sprouts (sometimes called suckers) spring up from the roots. A considerable colony of these young sprouts may often be seen quite surrounding the parent tree and extending many feet away from it. Many bad weeds, such as the field sorrel (*Rumex*) and the Canada thistle (*Cirsium*), are reproduced by roots. In case of desirable plants that can be propagated either by pieces of root or by seeds, it is generally better to use root cuttings, as they will grow much faster.

FIG. 24. Vegetative reproduction of the sweet potato

The potato was buried in moist sand and began to sprout, that is, to send out shoots from adventitious buds at various points. Each shoot may grow into a new plant. About half natural size

Among plants that you know, are there more instances of useful or of injurious kinds that are usually propagated by the root? Give examples.

PROBLEMS

1. When actively growing stems are cut off, do they "bleed" on both the upper and the lower cut surfaces? Why?

2. How could an experiment be made to show the exact amount of upward pull and of lateral pull which the anchorage of a plant will resist?

3. What practical advantage is taken of the powerful anchorage of shade trees?

4. Why must swamps be drained before most crops can be grown in them?

5. What kinds of plants would be useful in preventing the drifting of sand in dunes like those of figure 1?

6. What are some reasons why embankments, as of reservoirs and railroad rights of way, should be kept well grassed over?

7. Just where would you place soil fertilizers for prompt effect on old apple or pear trees?

8. Make a list of all the plants that you can find producing aërial roots, and try to explain their use in each case.

9. What common plants are almost always propagated by roots? What ones are propagated sometimes in this way and sometimes in other ways?

10. When roots are uncovered by the washing away of the soil, do they develop bark like that of the stem?

CHAPTER IV

MANUFACTURE, TRANSPORTATION, AND USE OF FOODS IN PLANTS

32. The problem of securing food. Plants, like animals, cannot continue to live and grow without nourishment, but like animals, they may secure the needed nourishment in a variety of ways. Reference has already been made to some of the ways in which roots, stems, and leaves are related to the plant's food supply, but we shall need to consider further the machinery and processes by means of which green plants manufacture the things that nourish them.

33. Structure of a leaf; epidermis. In Chapter II the general form of the leaf and some of its functions were discussed. A more detailed study of leaf structure and function is necessary for the discussions of the present chapter.

Most leaves consist of the petiole, or leafstalk, and the blade, or expanded portion. In some leaves there is no petiole; that is, the leaf is *sessile*, or rests directly upon the stem or branch that bears it. In some leaves the blade is divided into several parts, or leaflets. An undivided leaf is *simple*, and a divided leaf is *compound*. Leaves vary in size, from those that are so small that they are not readily visible, to those so large that they are several feet in width or several yards in length. In color most leaves are green, but they differ in strength of color, and a careful observation usually discloses a difference in greenness between the two leaf surfaces, or between different parts of the same surface. It is possible to observe within most leaves the more or less regularly arranged veins, or fibrovascular bundles, which are not green. Also on one or both leaf surfaces, as in the mullein, begonia, and thistle, there often develop outgrowths known as hairs.

From the upper and the lower surfaces of leaves such as those of live-forever, Wandering Jew, Easter lily, corn, and spiderwort one may peel a thin, almost colorless layer which is known as the epidermis (fig. 25). The epidermis is composed of cells more or less compactly arranged. Different plants show much variation in the way in which these epidermal cells fit together.

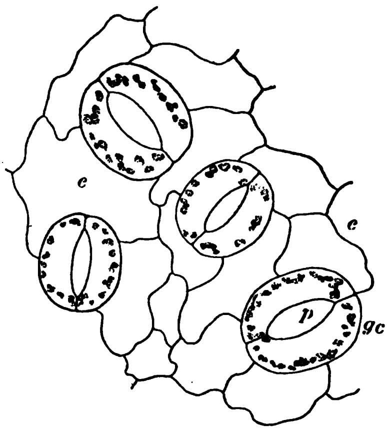


FIG. 25. A surface view of leaf epidermis from the geranium (*Pelargonium*)

Among the ordinary epidermal cells (*c*) are four stomata, each with two guard cells (*gc*) and the mouth of an air cavity (*p*). Considerably magnified

One or both epidermal layers may include special structures known as *stomata* (singular, *stoma*) (fig. 25). Usually, when viewed from the surface, the stoma is readily seen to consist of two crescentic or kidney-shaped cells with their concave sides facing one another, so as to leave an opening between the two cells. The opening is really the mouth of a larger space extending within the leaf. It is known as the *stomatal opening*, and the two cells that are about the mouth are known as the *guard cells*. Unlike other epidermal cells the guard cells are green. The stomatal opening serves as a place of entrance for the carbon dioxide used by the plant, though carbon dioxide may doubtless enter the plant with the water from the soil. The guard cells may also press closely together or may separate until a wide circular opening is formed, and in thus closing and opening they influence the interchange of air between the interior and the exterior of the leaf. Obviously this opening and closing also affects the interchange of such gases as carbon dioxide and oxygen, as well as the outgo of moisture from the leaf.

34. Internal structure of the leaf. An idea of the inner structure is best obtained by examining a cross section of a simple leaf. In general, three kinds of cells appear within the epidermis, and these are variously arranged in different kinds of plants. In simple leaves, such as that shown in figure 26, almost all the cells contain the green coloring matter, *chlorophyll* (meaning " leaf green "). These chlorophyll-bearing cells are long and are arranged side by side (*palisade* tissue) or are

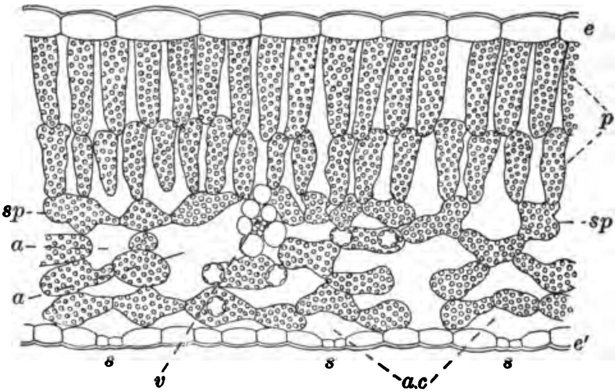


FIG. 26. Cross section of a geranium leaf

a, air space; *a.c*, air chamber; *e*, upper epidermis; *e′*, lower epidermis; *p*, palisade cells; *s*, stoma; *sp*, spongy parenchyma (usually spongy parenchyma has fewer chloroplasts than the palisade tissue); *v*, vein. Magnified 150 times. After drawing by Mrs. F. E. Clements

more irregular in form and loosely arranged (*spongy* tissue). Air spaces are abundant between these cells, but they are larger and more abundant in the spongy tissue than in the palisade tissue. When a single layer of palisade tissue and one of spongy tissue are present, the palisade tissue lies next to the upper surface of the leaf and the spongy tissue next to the lower surface; but frequently there is a lower layer of palisade tissue, not so well developed as the upper one. In cross sections of leaves the veins appear as masses of small, thick-walled cells closely crowded together and usually lying about midway between the upper and lower surfaces of the leaf.

35. Chlorophyll in the leaf. The so-called green cells of the leaf are not evenly green throughout, but contain special bodies (*plasts*, or *plastids*) in which the chlorophyll is held. These chlorophyll-bearing bodies, or *chloroplasts*, are often so numerous in the cells of the leaf as to make the cell appear to be almost of a solid green color, and when the surface of the leaf is observed, its appearance seems evenly green throughout.

It must be clearly understood that chlorophyll and the chloroplast are not the same. Plastids (plasts) may or may not contain chlorophyll, just as a sponge may or may not contain water. A plastid can properly be called a chloroplast only when it contains chlorophyll. When green leaves have stood in alcohol for a few hours, the chlorophyll is dissolved by the alcohol, the leaf is decolored, and the color of chlorophyll may readily be observed in the alcohol.

In summing up the structures of the leaf we may say that it usually consists of petiole and blade. The outer portions of the blade, both above and below, are the epidermis; in addition to the ordinary epidermal cells the epidermis contains special structures, the stomata, each of which ordinarily consists of two guard cells and a stomatal cavity; within the epidermis are the veins and the masses of green tissue — the palisade and spongy tissues; within the cells of the green tissues, in addition to other cell contents, are many plastids. These may contain chlorophyll; they are then known as chloroplasts.

36. Material for chlorophyll work. In the discussion of stomata it was stated that carbon dioxide may pass into the interior of the leaf. It was previously found that water is taken into the plant and carried through the stem. In the soil are many substances which are dissolved by the water, just as common salt or sugar would be. From this source there may pass into the plant compounds containing such things as nitrogen, potassium, phosphorus, sulphur, and iron. Carbon dioxide, which is secured through the surface of the leaf, is a gaseous substance which exists in the atmosphere,

ordinarily in the ratio of about 3 parts in 10,000 parts of air. Inside the leaf, therefore, is a supply of the so-called raw materials for food — water, carbon dioxide, and substances that were in solution in soil water.

37. The manufacture of food. Carbon dioxide and water must undergo changes before they can be used in nourishing and building up the plant. The sun shines upon the leaf and the chlorophyll absorbs some of the energy from the sun's rays. In some way, as yet unknown, this energy serves to break up the compounds water and carbon dioxide into the carbon, hydrogen, and oxygen of which they are made. The carbon, hydrogen, and some of the oxygen immediately unite again — not, however, into the compounds carbon dioxide and water, but into new compounds. These rapidly pass through several changes and may finally become sugar and starch. At present the changes that take place before starch and sugar are formed are not all known, but enough is known of them to show that they are quite intricate. Some of the oxygen resulting from the breaking up of water and carbon dioxide is set free and may pass out into the air. The oxygen thus set free by plants may be collected as shown in figure 27, and then tested.[1] This process that is carried on by green plants is a principal factor in maintaining the oxygen supply that is so necessary to the life of animals. Plants also use free oxygen in some of their later food-making processes. This series of occurrences, by means of which green plants under the influence of sunlight make foods such as starch and sugar from carbon dioxide and water, is known as *photosynthesis*. The word *photosynthesis* means "putting together by means of light."[2]

Sugar and starch (carbohydrates) may be used in the nutrition of the living parts of the plant; or, by the addition of

[1] If a test for oxygen is made, it is best to precede the ordinary test by an experiment with oxygen that has been prepared by the electrolysis of water. Test the oxygen so prepared with a lighted splinter, as more meaning will then attach to the test of oxygen set free by the plant.

[2] See Appendix, page 343.

some of the compounds of nitrogen, potassium, phosphorus, or other substances, these things may be made into more complex foods known as proteins. Many stages of the process of making these more complex foods are not known, and these are too intricate for extended discussion at this time. The leaf or other parts of the plant may be used as the place where proteins are made. They may be made immediately after the carbohydrates, or later, but sooner or later some protein food is as necessary to the continued life of plants as of animals.

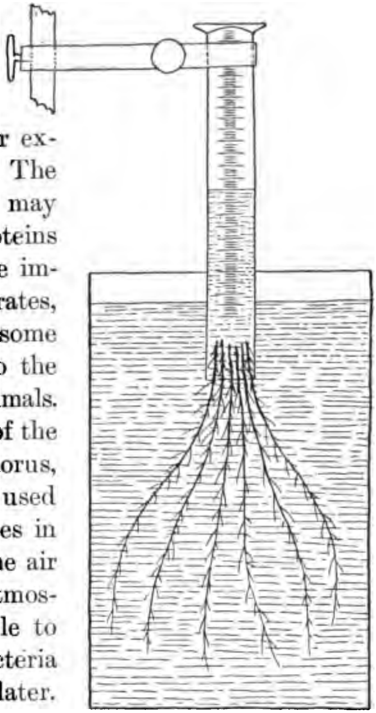


FIG. 27. Apparatus for collecting oxygen from working plants

Water plants are submerged with one end in the mouth of the graduate. Bubbles of oxygen pass upward from the cut ends of the stems and crowd out some water from the previously filled graduate. The ordinary test for oxygen—with a burning stick—will determine whether it is present. In such an experiment care must be taken to see that there is plenty of space about the collecting tube, to permit free passage of the gases that are in the water. After Ganong

The soil is the usual source of the nitrogen, potassium, phosphorus, and other substances that are used in addition to the carbohydrates in making proteins. Although the air is 78 per cent nitrogen, this atmospheric nitrogen is not available to plants, except to certain bacteria which are to be discussed later. From the soil, compounds containing nitrogen and other substances may be dissolved in water and then carried into the plants. Fertile soils are those which contain in available form large quantities of the things which plants use for food-making. Replenishment and growth of new parts can take place only by means of foods, and since the plant makes its own supply, the importance of the process is very great.

Often green plants make more food than they use at the time, and this surplus food may be stored or reserved in some way. Stored food may or may not be used later by the plant, and may oftentimes become the food of other plants, of animals, or of men.

38. Food transported by the plant. In all except the simplest plants the reserve food is carried from the cells in which it was manufactured, into other cells. In plants with fleshy leaves, like the houseleek, the century plant, the common purslane, and many others, the greater part of the stored starch and other nutritive materials has only been carried to the leaf interior from the outer portions of the leaf, where photosynthesis and other manufacturing processes go on. The distance traversed may be only a small fraction of an inch, but in case much of the food is stored in underground parts of the plant, it may have been carried for long distances — in large trees, sometimes more than a hundred feet before it reaches the root at all.

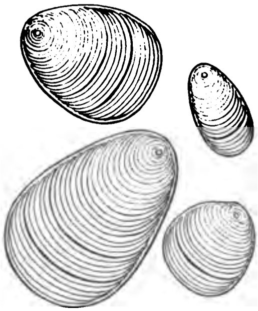


FIG. 28. Starch from rootstock of canna

Magnified 300 diameters

39. Form in which food is transported. As already stated, one of the products of photosynthesis in most plants is starch. This is deposited in or about the chloroplasts, during their exposure to daylight, in very minute grains. In the course of the night these disappear, so that testing a leaf with iodine[1] shortly before daylight usually gives no result. A leaf cut off from the stem before nightfall, however, responds readily to the iodine test for starch in the morning. This, of course, shows that the starch made during the day remained in the leaf cells, where it was formed. It is very generally true that starch carried from any part of the plant to another part is first changed to sugar and travels in the form

[1] This turns starch grains blue or almost black.

of a weak solution of sugar in water. On its arrival at the storage region (for example, the tuber of the potato plant) the dissolved sugar is reconverted into starch by the action of minute, colorless corpuscles of protoplasm, known as *leucoplasts*. The starch grains deposited for storage (fig. 28) are many times larger and show a far more definite structure than those formed in the chloroplasts during photosynthesis.

40. Diffusion and osmosis. It is clear that plant food must pass from within certain cells into others, and the way in which this occurs may be made clearer by the use of simple illustrations. If some dried raisins or prunes are placed in pure water it will soon be noted that the outside membranes, which at first were contracted and wrinkled, have become distended. Water has passed through the fruit coating and is retained within it. After a longer time it will be found that the water outside the fruit has become sweet, owing to the outward passage of dissolved sugar from within the fruit. If a little molasses is poured into a straight-sided jar, and a disk of porous paper is placed so as to cover the molasses (to prevent instantaneous mixing), and water is then carefully poured upon the disk of paper, the water will for a considerable time appear clear and colorless. Only after some hours will the molasses rise and mingle much with the water, or the latter perceptibly thin the molasses. This process, by which two liquids in contact become mixed by the interchange of inconceivably minute portions (molecules) of both liquids, is called *diffusion.* The tendency is for the two liquids to become completely intermingled, so that at last all portions of the mixture are of precisely the same composition. Similarly, if a dense liquid surrounds a plant cell, water passes more rapidly outward than inward, and the remaining internal parts of the cell collapse, or *plasmolyze* (fig. 29), because of the loss of water. This merely illustrates the fact that interchange of liquids may take place in either direction through a membrane, but is more rapid from the less dense to the more dense liquid. The mingling of liquids that are separated by a partition which one or both of them

can penetrate has received the special name of *osmosis*. Osmosis is not quite so simple as diffusion, since the movement of particles of the liquids is a good deal affected by the nature of the partition. In Chapter II it was stated that soil water may be taken up by root hairs. It may now be seen how osmotic action affects this process of taking up water by root hairs. By osmosis soil water may pass through the root-hair walls into the interior of the root hair and thence to other root cells. Obviously, when the liquids of the soil are more dense than the liquids within the root hairs, the root hairs will lose some of their water to the soil outside, and if enough water is lost in this way, the contents of the root hair may become plasmolyzed.

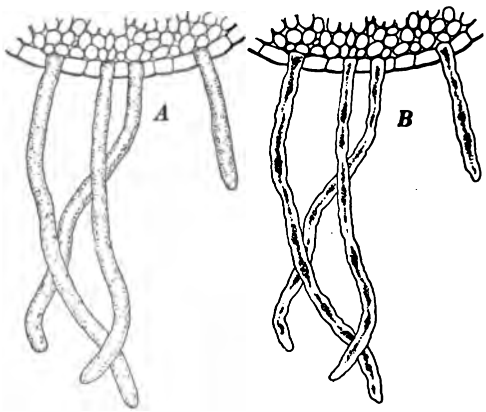


FIG 29. Root hairs

A, in normal condition; *B*, the same root hairs after being treated with a solution of common salt

41. How food is carried through plants. Applying the principles of osmotic action to the case of a starch-loaded leaf, it is evident that, as fast as the starch grains temporarily deposited in the chloroplasts of the leaf are changed into sugar, some of the sugar in the denser cell sap thus produced will pass on to the more watery sap of adjacent cells. From these cells, in turn, portions of sugar will pass on to still more distant cells. In a similar way, when a potato tuber is planted and begins to sprout, the sugar formed from the reserve starch in the potato passes into the more watery sap contained in the sprouts. This sap is constantly losing sugar that is used as building material for the young growing stems and leaves,

and the supply of materials for growth is maintained by the addition of new portions of sugar coming from the tuber.[1]

42. Channels through which food is transported. Many kinds of living tissue serve as channels for the conveyance of food from one part of the plant body to another. The main route for the transportation of food in flowering plants is through special tubular cells which form the *sieve tubes*, so called from the perforated plates found at the ends or along the sides of the nearly cylindrical cells of which the tubes are built up. In dicotyledons these sieve tubes occupy a region of the stem immediately outside of the cambium, as shown at *o* in figure 42, *A* and at *si* in figure 43. The fact that most of the plant food prepared in the leaves is carried down through the sieve layer of the bark is well shown by the behavior of a willow cutting from which a ring of bark has been removed. If the cutting is stood with its lower end in water but with the girdled part out of water, enough constructive material will pass down through the sieve layer to send out roots from the upper edge of the ring, but few or none will appear at its lower edge. In the meantime water is freely carried upward through the sapwood. In early times the process of clearing woodlands for farming purposes was made less laborious by girdling the trees, which soon died and at length fell and were burned. Would the girdling process be more effective if a good deal of the sapwood, as well as the bark, were removed from the ring? In woody dicotyledonous stems there are radiating lines of cells (medullary rays) running outward from the center toward the circumference of the stem. Food is stored in these rays, and they are also lines of conduction of foods.

43. Food storage. In the trunks of trees stored food may be present in various forms, as starch, sugar, oil, and proteins. In the autumn many kinds of sapwood turn deep blue or black

[1] It is not possible here to go into details concerning the transportation of other kinds of plant food than starch and the sugars. That of proteins is especially difficult to trace.

if tested with iodine for starch. During the winter much of this starch is often converted into sugar or oil. The presence of proteins in wood is so general that the cheaper grades of white paper, largely made of wood pulp, at once turn yellow on being moistened with nitric acid (the protein test). When thus tested, paper made wholly of cotton or of linen rags shows little change. The plant food stored in wood is most abundant in the younger portions (sapwood) and above all in the cambium layer.

Underground stems and roots (fig. 30) often contain large quantities of stored food and are thus useful in tiding the plant over that period of the year when no food can be made. In the same way they are of service in storing water, as has already been shown (sect. 21). There are many shade plants, such as trilliums, dogtooth violets, wild ginger, May apple, and others, which leaf and flower early in the spring and do a large part of the storing of food for the next season in their rootstocks, tubers, or bulbs, before the trees under which they grow are in such full leaf as to shut out the abundant light necessary for photosynthesis.

Fleshy leaves often contain much stored food, as in the familiar century plant, which, after storing food for fifteen years or more, may use this food in producing an immense flowering stalk and many flowers and seeds. By the end of the flowering season the leaves, in the case of century plants that were tested, had lost more than 90 per cent of their weight. This flowering stalk may reach a height of over 33 feet and a weight of some 500 pounds. Its average growth in height during the month of most rapid elongation has been found to be about $5\frac{1}{2}$ inches a day. Not only the plant food but also nearly all the water for this rapid growth is furnished by the leaves.

44. Relation of food and water storage to duration of life. It is usual to divide plants, according to their duration of life, into three classes: *annuals*, those living one year or less; *biennials*, those living two years; *perennials*, those living more than two years. The boundaries between these classes are not always definite. For example, winter wheat is an annual,

though it does not seed until the next summer after it is planted; and the cotton plant, the lima bean, the tomato, and the castor bean are instances of plants which with us are cultivated as annuals, but which in warm climates live several years, the castor bean growing into a large, almost tree-like shrub. Plants which live for more than one year usually have food stored in their roots.

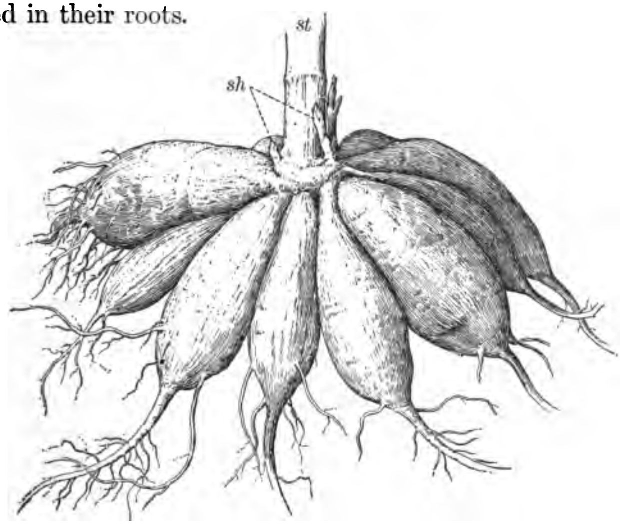


FIG. 30. Clustered, fleshy roots of the dahlia, with much stored plant food, in early spring

st, remains of last year's stem; *sh*, young shoots beginning to sprout from upper ends of roots. One fourth natural size

Such biennials as beets, carrots, and parsnips store up much food in the root [1] during the first summer's growth, and form a large tuft, or rosette, of leaves, but do not develop much stem aboveground. During the second summer the stored food is consumed in the production of leafy stems bearing flowers and fruit, and in the autumn the root appears quite withered and nearly dry.

Herbaceous perennials, like the dahlia (fig. 30) and the common rhubarb, store food in the root during the summer

[1] The underground part of the carrot and the parsnip is part stem and part root.

and consume part or all of it in the growth of the following spring. Trees and shrubs in temperate or cold climates store starch and other foods in the roots, as well as in the stem. It is the stored food in the root that enables such plants as rhubarb, the peony, some buttercups, sweet cicely, the dandelion, and many others to make a quick growth in the spring, before the weather is warm enough for the manufacture of much plant food. The starch, sugar, and proteins which abound in many roots or root-like portions of plants make them valuable for food, as in the case of beets, turnips, carrots, parsnips, sweet potatoes, salsify, and the cassava plant, from which tapioca is made.

45. Digestion and assimilation. Plants as well as animals must make solid foods into solutions before these foods can become parts of the living protoplasm. The processes which make these solids into solutions are known by the general name of *digestion.* Digestive processes vary widely in different living things. Animals usually have special organs for this work, but plants do not have them. The process is essentially the same in both, however, though it may be much more complex in some higher animals than in plants. Plants form certain chemical substances known as *enzymes* (see sect. 157), which operate in ways that are little understood, but which result in digesting foods.

By a process known as *assimilation* digested foods may be taken into living protoplasm and made a part of it. What occurs in assimilation no one really knows. Digested food becomes living protoplasm, and in so doing it becomes more complex in structure. Thus far it has been impossible for scientists to follow the process closely enough to determine the changes which assimilation makes, though it is known that living substance is the outcome.

46. Respiration. Food that has been digested and assimilated, thus becoming living tissue, is later changed by the process known as *respiration.* It is common to associate respiration, in both plants and animals, with the interchange of

gases between the exterior and the interior of the living body — between the lungs and the air in the case of the higher animals and between the leaves and the air in the case of the higher plants. This interchange is, however, no longer regarded as the fundamental thing in respiration, since respiration takes place in active, living protoplasm in all parts of the plant. It consists of decomposition of protoplasm or of some of its parts, or (as is supposed by some botanists) it may consist of decomposition of food materials that have not yet become assimilated so as to become protoplasm. Through respiration complex plant substances are broken down, and the energy released by this decomposition is the energy by means of which plants carry on their work. Energy in the form of heat is also one of the results of respiration. Respiration may occur in the absence of free oxygen, but it is more complete, and thus releases more energy, when oxygen is present. When respiration is complete, it results in the formation of various compounds, of which carbon dioxide and water are conspicuous. Carbon dioxide and water may be carried away from the plant through the leaf or other parts, and the oxygen supply may enter in the same way. It is evident, however, that the transfer of these gases is merely an incident associated with the real respiration, which consists in the decomposition of complex substances and the release of energy therefrom. It is also evident that, so far as respiration is concerned, plants and animals behave in the same way. It should be noted that in photosynthesis green plants utilize carbon dioxide, though they, like other plants and animals, may produce carbon dioxide as one of the products of respiration.

47. Importance of the food cycle in plants. The importance of the food cycle of green plants can scarcely be overestimated. The human race depends, directly or indirectly, upon photosynthesis and the storage of food by plants. Men have selected and improved those plants which produce the most desirable food in the largest quantities. They have studied, and must continue to study, the conditions of soil and the climatic

conditions under which plants produce most abundantly. They must study and improve those plants which are found to perform their nutritive functions in such a way that large amounts of desirable food are produced economically.

The island of Chung-ming, at the mouth of the Yangtze River in China, has an area of 270 square miles. It has but one large city, yet the whole island has a dense population. The inhabitants have made such a study of the productivity of plants that the island is said to support a population of 3700 people per square mile. Our own rural population of 61 per square mile of improved land suggests by comparison the necessity of further study of the food cycle of plants and of the conditions under which our economic plants thrive best.

48. Independent and dependent plants. So far in this chapter we have spoken only of plants that have chlorophyll and can make their own food from materials that are not ordinarily regarded as nutrient substances; that is, we have discussed only *independent* plants. But there are many plants that do not possess chlorophyll, and even some that do possess it, that are *dependent* for their food upon the chlorophyll work of plants similar to those we have already discussed. Then some plants are dependent, not for food, but in other ways. Some dependent flowering plants, like the woodbine, or Virginia creeper, are almost independent. A woodbine may grow in the open and attain its full size, but in dense woodlands grapevines, woodbines, and many other climbers can only make a normal growth by climbing upon the trunks of trees and so raising themselves into the light.

49. The food supply and dependency in flowering plants.[1] The principal groups into which dependent flowering plants are divided are as follows:

1. Lianas, or climbers.
2. Epiphytes, or plants which rest upon other plants.
3. Saprophytes, or plants which live on the products of the decay of organic matter.

[1] Dependency among lower plants is discussed at length in later chapters.

FIG. 31. Spanish moss, an epiphytic flowering plant

These plants often grow in large numbers upon the branches of trees in the southern part of the United States

4. Parasites, or plants which live upon other living plants or animals (known as host plants or animals).

5. Carnivorous plants, or those which capture small animals, such as insects, and live wholly or partly upon them.

Lianas, which were mentioned in the preceding section, get their living without receiving from other plants any benefit except that of position. The other groups (2–5) are discussed in the following sections.

50. Epiphytes. Unfortunately for students in temperate climates, flowering epiphytes are mainly confined to the tropics. The Spanish moss (fig. 31) is one of the few exceptions. A visit to any large greenhouse in which orchids are kept will, however, suffice to give a fair idea of the appearance of some

FIG. 32. Indian pipe (*Monotropa uniflora*), a symbiotic saprophyte

The plants are white from lack of chlorophyll

of the most characteristic plants which live upon the trunks or branches of trees. Since these plants usually have little or no permanent water supply about their roots, they must be provided with means of absorbing water rapidly during rains, and of retaining it between one rainfall and the next. The Spanish moss, which is rootless, takes up water along the surface of the stems by the aid of special absorbent hairs which grow from the epidermis. This plant can become almost dried up without permanent injury. Other epiphytes, as orchids, have specialized water-absorbing tissues upon root, stem, or leaf surfaces, and from these tissues water escapes slowly in dry weather.

51. Saprophytes. In general, the seed plants which are saprophytes occur only in the forest or under shrubs. It is in such situations that plants find a most abundant supply of *humus*, or decaying organic matter. *Complete saprophytes* — that is, those which

Fig. 33. A single Indian pipe plant (*Monotropa uniflora*)

Note the slender stem and reduced leaves

Fig. 34. Clover dodder, parasitic on red clover

***A*, habit sketch of part of the parasite and the host; *B*, portion of stem of the dodder, showing protuberances from which haustoria pass into the stem of the host; *C*, a single flower of the dodder. *B* and *C* considerably magnified. Modified after "Flora Danica"**

cannot exist without an abundant supply of soluble organic matter in the soil or sub-stratum — are always pale, or even white, from partial or complete absence of chlorophyll (fig. 32). Their leaves are small and scale-like (fig. 33). Their roots are usually short and have little tendency to branch. Some

saprophytes have fungi growing upon their roots in such ways as to assist in securing food. These are called *symbiotic saprophytes.* The Indian pipe (*Monotropa*) often has these root fungi (mycorrhiza).

Partial saprophytes, among flowering plants, are not easily recognized by their form and color, but may be known by their inability to flourish without considerable humus in the soil.

52. Parasites. The dodders are the most familiar flowering parasites. One of the commonest species is abundant in the central and northeastern states, its thread-like, golden-yellow stems forming great tangled masses on many kinds of plants, as clover, goldenrods, and willows, that grow in damp places. The dodders (fig. 34) and some root parasites, such as the beechdrops, squaw-root, and cancer-root, are *complete parasites* and have no green foliage. Other plants, such as the mistletoe (fig. 35), have green leaves and do photosynthetic work, but depend on the host for water and the mineral substances dissolved in it. Such plants are called *partial parasites.*

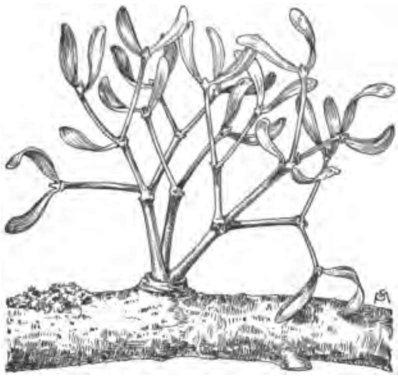


FIG. 35. Mistletoe growing upon a branch of an apple tree
After Bonnier and Sablon

53. Damage inflicted by parasites. Many parasites take so much water and plant food from the host that they may cause serious injury to cultivated plants and to forest trees. The flax dodder and the clover dodder often do great damage to crops in this country and in Europe, and another species[1] is sometimes troublesome in fields of alfalfa. In the southwestern states the American mistletoe is so injurious to dicotyledonous trees that it is often necessary to cut it away from

[1] *Cuscuta arvensis.*

the trees to enable them to thrive. The European mistletoe causes much damage to apple trees in northern France and in the Tirol.

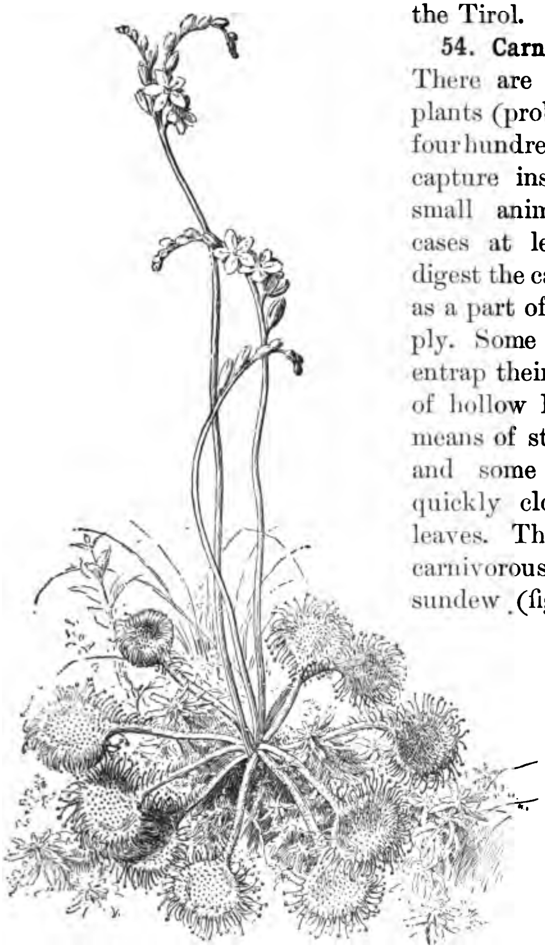


FIG. 36. The sundew, a carnivorous plant

54. Carnivorous plants. There are many kinds of plants (probably more than four hundred species) which capture insects and other small animals. In some cases at least they may digest the captured animals as a part of their food supply. Some of these plants entrap their prey by means of hollow leaves, some by means of sticky secretions, and some by means of quickly closing, trap-like leaves. The best type of carnivorous plant is the sundew (fig. 36). This is a low marsh plant having hairy leaves and a slender flower stalk, on which are borne small white flowers. In one widely distributed species the leaf consists of a narrow blade tapering into a moderately long leafstalk. On the inner surface and around the margin of the blade are borne a number of short bristles, each terminating in a knob

which is covered with a clear, sticky fluid. When a small insect touches one of the sticky knobs, it may be held fast, and in that case the hairs at once begin to close over it. The insect soon dies and usually remains for many days, while the leaf pours out a juice by which the soluble parts of the insect are digested. The liquid containing the digested portions is absorbed by the leaf and contributes an important part of the nourishment of the plant, while the undigested fragments, such as legs and wing cases, remain on the surface of the leaf or may drop off after the hairs let go their hold on the captive insect. The pitcher plants have cylindrical, liquid-containing leaves, with inner hairs so arranged that insects get into the leaves very easily and get out with great difficulty, if at all. The leaves of the Venus's-flytrap close so quickly that they sometimes catch insects which may come in contact with them.

PROBLEMS

1. Which are greener, leaves which are densely shaded or those which are exposed to the sun? What makes the difference?

2. Will alcohol dissolve the chlorophyll more quickly from densely shaded or from openly exposed leaves? Why?

3. Under what conditions could a field of corn lose water to the soil instead of securing water from the soil?

4. What would be the effect upon animal life if green plants should manufacture no more food than they consume in their own growth?

5. Leaves often give a strong starch reaction in the late afternoon and none in the early morning. Can you account for this?

6. It was found by some students that a corn plant elongates about four times as much between 6 P.M. and 6 A.M. as between 6 A.M. and 6 P.M. Can you account for this fact?

7. Fields of grain are often more or less wilted at noon on hot summer days and regain their turgor at night even when no rain has fallen. Can you account for this fact?

8. In trying to kill plants in the lawn or trees in the cultivated fields people sometimes put salt upon the roots or stumps. What is the botanical explanation of this practice?

9. Can you arrange an apparatus to test the pressure with which maple sap flows from a cut branch?

10. Can you explain the fact that you cannot get seed from beets and carrots the same year that the plants are grown from the seed?

11. It is often stated that one difference between plants and animals is that plants use carbon dioxide and throw off oxygen, and animals use oxygen and throw off carbon dioxide. In what ways is this statement correct and in what ways is it an error?

12. In what sense is it true that the sun is the source of the energy by means of which plants and animals do their work?

13. In what ways is it important to your community that the people should know something about photosynthesis?

CHAPTER V

THE STEM AND THE LEAF

FIG. 37. Beefwood, *Casuarina*, an Australian switch plant destitute of foliage leaves and depending on the chlorophyll-containing cells of the bark for photosynthesis

Photograph by Robert Cameron

55. Work of the leafy shoot. How plant food is made from raw materials has been briefly explained in Chapter IV. In almost all of the higher plants this food-making is carried on by the coöperation of the stem and the leaf. Taken together, they are known as the *shoot*, so that the parts of a flowering plant (before it begins to flower) are root and shoot.

56. Photosynthesis in the stem. Among seed plants in general it is the leaves that do by far the greater part of the work of photosynthesis, but some plants, as the cacti (fig. 66), are practically leafless[1]

[1] That is, they have no leaves which can do any food-making or which at all resemble ordinary leaves.

JULIUS SACHS

Julius Sachs, a noted German botanist (b. Breslau, 1832; d. Würzburg, 1897), was a most careful observer of the ways in which plants live and work. He had a remarkably clear and forceful style of writing and an unusual ability in making illustrations. As investigator, writer, and teacher he organized the somewhat disconnected discoveries of others and, adding his own discoveries, established the science of plant physiology. His textbooks were unsurpassed in influence and gave to many students their first general view of botany. He published many important contributions to our knowledge of germination, the work of chlorophyll, and other processes of food-making and food transportation

all the year round, and in these photosynthesis is carried on by the green layer of the cortex beneath the epidermis of the stem.

In many dry countries there are switch plants, which either bear a few little leaves during a small part of the year or are entirely leafless, as is shown in figure 37. Like the cacti, such plants, and others with flattened stems and little leaf surface (fig. 38), do the greater part or all of their photosynthetic food-making in the green cells of the cortex of the stem.

Many of our common forest trees and shrubs do food-making in the green layer of the bark of the young twigs, until this is shut away from the light by layers

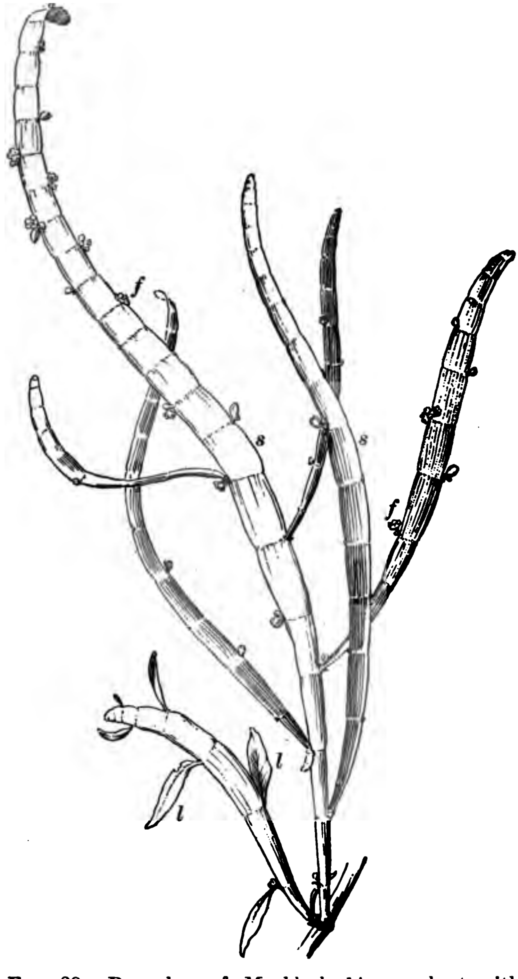


FIG. 38. Branches of *Muehlenbeckia*, a plant with scanty leaf surface and flattened stems which do most of the photosynthetic work of the plant

f, flowers; *l*, leaves; *s*, stems. One half natural size

of cork which form outside the green bark. Photosynthetic work is also done by the stems of most common annual plants of the farm and garden, such as corn, beans, peas, and potatoes.

FIG. 39. Twigs of coffee tree, showing how leaves are supported so as to give them complete exposure to light

57. The stem raises leaves into the light. Competition for light is extremely common among plants. One of the main reasons why the surface of the earth in a very dense forest — the *forest floor*, as it is called — is comparatively bare of flowering plants is that they cannot get enough light there to live. In a cornfield it often seems as if the weeds were

going to outstrip the corn, but if they are kept down until the corn has begun to shade the ground well, there will be little further trouble from most weeds. If, however, the corn is cut early for green fodder or for ensilage, a rank crop of weeds will spring up between the rows. So foxtail and other weeds begin to flourish among the stubble as soon as oats, wheat, or rye have been reaped.

The stem, then, by lifting the leaves up into the sunlight and supporting them there in favorable positions (fig. 39), gives them a chance to do photosynthetic work, so that the whole plant prospers. Even climbing plants like the English ivy (fig. 40), with stems that bend away from the light toward a supporting rock or tree trunk, turn their leaves to face the light. There are many plants — creeping kinds, like white clover, and those with flattish clusters of leaves, like the dandelion — which flourish in places

FIG. 40. An English ivy (*Hedera*) grown in front of a south window

WW, the line of the window casing; all to the left of this is unlighted wall. The tips of the shoots (*t*) avoid the light; the young leaves (*l*) have assumed no definite position; the mature leaves are nearly at right angles to the light coming from the direction of the arrow

where they can cover the surface of the ground closely enough to prevent too severe competition from plants that might shade them.

As a result of this competition for light, plant stems often become greatly lengthened. Any one who is observant and familiar with things out of doors must have noticed the difference in form (*habit* it is called by botanists) of such plants as giant ragweed (*Ambrosia trifida*) and hemp; they grow tall and little branched when in dense clumps, but low and spreading when they stand alone. Full-grown trees, such as pines, are nearly branchless for most of their height when growing in dense forests, but are low and broad-topped, with many lateral branches, when growing alone in a pasture.

58. Plants blown down by wind. Most farmers who grow any kind of grain have had losses from lodged grain — that is, from crops which have been more or less completely blown down by a windstorm, and especially by a wind accompanied by a heavy rain. Forest trees are often blown down by severe winds (fig. 41). Where they pass through forest tracts, the violent rotary storms commonly known as cyclones frequently leave behind them windfalls, in which the tree trunks lie in piles for long distances. Individual plants of any kind of grain, and tall, slender forest trees growing under usual conditions, are greatly protected by their neighbors. The whole mass of plants, standing as close together as they do, intercepts much of the wind, so that the single plant is exposed to only a small fraction of its total force.

59. Growth in length of stem. Under favorable conditions the younger regions of the stem continue for some time to increase in length. The rate of growth varies greatly in different plants: the giant ragweed and certain kinds of sunflowers may grow to a height of 10 or 12 feet, and climbers like gourds and hops, to a length of perhaps 40 feet, in a single summer. On the other hand, pine seedlings, during their first summer, grow to be only from 1 to 3 inches high, and oak seedlings less than 5 inches. For a time the growth

per year continues to increase, and then diminishes. For example, the long-leaf pine (fig. 229) grows only about $\frac{3}{4}$ inch the first year. For the first fifty years it makes an average annual growth of 14 or 15 inches; for the next fifty years, 4 or 5 inches; and from one hundred years to extreme old age, about $1\frac{1}{2}$ inches. It usually lives about two hundred years.

FIG. 41. An isolated white oak tree destroyed by a violent windstorm

Photograph by Paul Sargent

The growth of the younger portions of most plants is quite unequal, as may be learned from the study of a rapidly growing stem, such as the morning-glory.[1] It will also prove interesting to measure such plants as corn, broom corn, hemp, and pole beans, to determine whether they elongate more by day or by night, and during warm or during cool weather.

[1] For an illustration of this unequal growth, see Bergen and Davis, Practical Botany, p. 17. Ginn and Company, Boston.

60. Internal structure of the young dicotyledonous stem.[1] It is a difficult process, involving much careful work with the microscope, to trace the earliest steps in the development of stem structure in the seedling plant. It is therefore better, for our purpose, to begin with the study of the stem at the end of the first season's growth.

In early spring, before the buds begin to open, a twig of willow, alder, or hickory is readily stripped of its bark. When split through the middle it shows a hollow cylinder

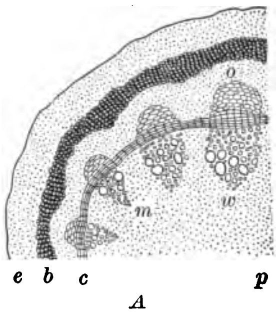


FIG. 42, *A*. Diagrammatic cross section of one quarter of a one-year-old stem of Dutchman's-pipe (*Aristolochia*)

e, region of epidermis; *b*, hard bast; *o*, outer, or bark, part of a bundle (the cellular portion under the letter); *w*, inner, or woody, part of bundle; *c*, cambium layer; *p*, region of pith; *m*, medullary ray. The space between the hard bast and the bundles is occupied by thin-walled, somewhat cubical cells of the bark. Magnified about 15 diameters

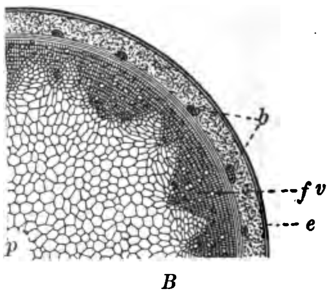


FIG. 42, *B*. Diagrammatic cross section of one quarter of a sunflower stem

p, pith; *fv*, woody, or fibrovascular, bundles; *e*, epidermis; *b*, bundles of hard-bast fibers of the bark. Somewhat magnified

of wood inclosing the cylindrical pith. These structural constituents — bark, wood, and pith — make up almost the entire bulk of the stem.

Examined in section by the aid of a good lens, young dicotyledonous stems are readily seen to be classifiable into two

[1] See also sections 61–65. The stems of many gymnosperms — for example, trees of the Pine family — in their general structure much resemble the dicotyledonous stems. For a general account of the stem structure of dicotyledons and monocotyledons see Coulter, Barnes, and Cowles's "Textbook of Botany," Chap. iv, A. ANGIOSPERMS.

groups: one with *no continuous woody cylinder*, like the stem of such a climber as the Dutchman's-pipe (fig. 42, *A*), and one with *a continuous woody cylinder*, like that of the sunflower (fig. 42, *B*). The real difference between the two kinds of stem is that, like most climbers, the stem of the Dutchman's-pipe begins the season's growth with a set of separate fibrovascular bundles which remain separate, while in the sunflower the bundles are at first separate but soon join each other. The boundary between bark and wood is a layer of thin-walled cells (*c*, fig. 42, *A*), the *cambium layer*. It is this cambium, its cells filled with mucilaginous protoplasm, that makes up the slimy layer just outside the wood, from which the bark peels so readily in early spring, when boys are making whistles or stripping off sheets of slippery-elm bark. It is important to notice that each fibrovascular bundle consists of an outer portion, *o*, which belongs to the bark, and an inner portion, *w*, which belongs to the wood.

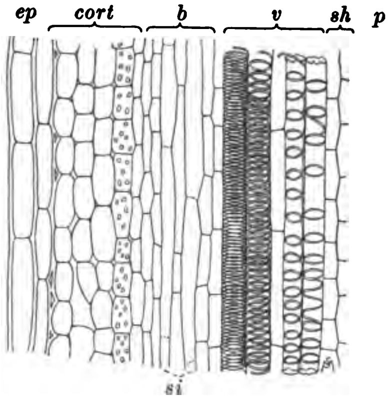


FIG. 43. Lengthwise section of a young dicotyledonous stem

ep, epidermis; *cort*, cortex; *b*, bast; *v*, vessels; *sh*, sheath surrounding pith; *p*, pith; *si*, sieve cells of the bast. Magnified about 90 diameters. After Bonnier and Sablon

A much better idea of the details of structure of the several regions of the stem can be gained from a lengthwise section, like that shown in figure 43, than from cross sections, like those of figure 42.[1] The uses of some of the parts shown in figure 43 are briefly stated on the following page.

[1] Since the type of stem structure shown in figure 43 is not exactly like that of the other two figures, it will not be possible to identify all the kinds of cells shown in figure 43 with those of the other two. Note especially that in figure 43 the cambium is not readily distinguished from the overlying tissues, and that no distinct layer of heavy-walled bast fibers is found.

1. The epidermis (*ep.*) serves as a protective covering for the young stem and, to a considerable extent, prevents it from becoming dried up.

2. The layers of cork cells soon formed just beneath the epidermis (not separately shown in the diagram) prevent loss of water and consequent drying up.

3. The layers of green cells which at first directly underlie the epidermis (not distinguishable in the diagram) are useful in the manufacture of plant food.[1]

4. The fibrous cells of the hard bast give toughness to the stem.

5. Certain thin-walled tubes (*si*) of the outer portions of the bundles carry manufactured plant food in liquid form downward, or toward the roots.

6. The cambium layer (in figure 42, *A* shown proportionally thicker than it really is) grows and forms new bark on its outer side, while on its inner side it forms new wood (see sect. 64).

7. The vessels, or ducts (*v*), of the bundles carry water upward, or toward the leaves. The fibers, which constitute a considerable portion of the wood part of the bundles, stiffen the stem and make it tougher.

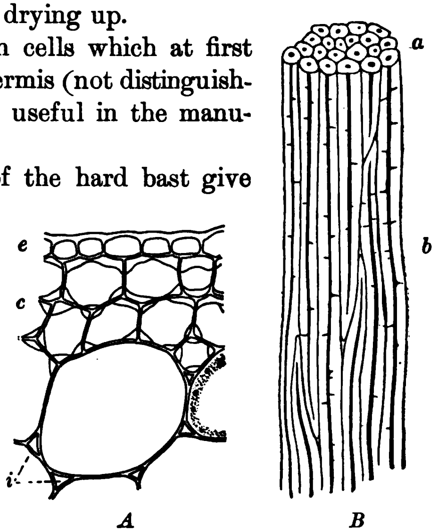


FIG. 44. *A*, strengthening and other tissue from stem of balsam (*Impatiens*); *B*, a group of hard-bast fibers

e, epidermis; *c*, collenchyma; *i*, intercellular spaces between large parenchyma cells; *a*, cut-off ends; *b*, lengthwise section of fibers. Greatly magnified. *A*, after Strasburger; *B*, after Tschirch

61. Strengthening cells. The cells which serve to stiffen or toughen the roots, stems, and leaves of plants belong to several different types. The two kinds shown in figure 44 are

[1] See section 56.

commonly found in the bark of dicotyledons and are often the main factors in strengthening young stems. *Collenchyma cells* (*A*) are like the thin-walled cells of the pith, but are reënforced at the angles, just as some packing boxes have strips of board nailed fast on the inside of the box at the junctions of the sides. *Bast fibers* (*B*) are extremely slender tubes with closed and pointed ends, much like a piece of thermometer tubing drawn to a point in a gas flame and thus closed. Collenchyma gives moderate stiffness to the parts in which it occurs and is highly elastic, so that it does not hinder the growth of the stem which it incloses. Bast fibers are flexible but very tough, and therefore enable the parts of the root, stem, or leaf in which they occur to resist being pulled apart. In many stems, particularly those which are more than a year old (fig. 45), a great part of the total strength is due to the presence of several kinds of fibers, of which the wood is largely made up.

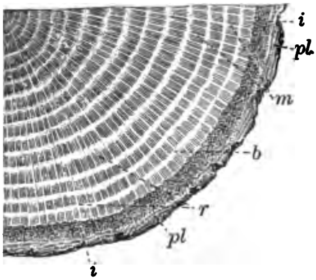


FIG. 45. One quarter of a cross section of a stick of oak wood

m, medullary rays, running from bark to pith; *r*, annual rings; *b*, boundaries between rings, porous from presence of many ducts; *i*, interior fibrous layers of dead bark; *pl*, hard plates of dead bark splitting away from each other but attached to bark beneath. Reduced

Which stem is more like a wire cable in its structure, that of Dutchman's-pipe (fig. 42, *A*) or that of the sunflower (fig. 42, *B*)?

62. Stiffness of stems. It is a familiar fact that a metal tube is stiffer than a solid rod of the same kind of metal and the same weight per foot of length. So in many plants, just as in the long bones of animals, the stems are at once stiff and light, because the material is arranged in the form of a tube, as in the bamboo, the straw of the small grains, and such flower stalks as that of the dandelion. In other cases, as in the cornstalk and in the stems of elder, the harder parts of the stem constitute a tube inside of which is much soft, light pith.

63. Limited thickening of annual stems. In stems of large dicotyledons which die to the ground every year, such as the sunflowers, ironweeds, hemp, and giant ragweed, growth in thickness goes on throughout the summer. The outer cells of the cambium continually split up by the formation of tangential partitions parallel to the bark, and so form new layers of bark. In a similar way and to a still greater extent the inner cells of the cambium form new wood, and thus the stem goes on increasing in thickness. But in such plants as those just mentioned the activity of the cambium is strictly limited; after it has given rise to a certain amount of new tissue, growth stops and the stem dies down to the ground. The death of annual stems in the autumn is often thoughtlessly supposed to be due to the arrival of winter, but it occurs just as certainly, and often after a briefer period of growth, in regions where there is no cold weather.

64. Annual thickening. In stems such as those of dicotyledonous trees and the trees of the Pine family and other cone-bearers, which live for many years, the cambium forms each year a new layer of bark and one of wood. These annual layers are usually more noticeable in the wood than in the bark, because the wood cylinders thus formed remain closely joined together (fig. 45). The newer, lighter-colored portions of the wood are known as *sapwood*, and the older portions, often darkened by the deposit of coloring matter, are known as *heartwood*. Not infrequently the heartwood decays and leaves the tree hollow.

How old is the stick of wood shown in figure 45? Did it grow at the same rate during all the years of its life? Discuss this question. Why is the name *annual rings* not an accurate one? What are they really? Is each year's growth uniform all round the stem? Had this stem any branches in the portion shown by the section? How does figure 46 suggest a method of determining the age of the stem at the time when a branch began? What seems a probable cause of the death of the branch, figure 46, *b*?

The hard-wood trees show great differences in the rate at which their trunks increase in thickness. Poplars, basswoods, willows, and red oaks, growing in good soil and unshaded, may for forty or fifty years form annual rings as much as three eighths of an inch thick, but old beeches and sugar maples in the forest, after they have passed the hundred-year limit, often grow not more than about one sixteenth of an inch per year. When very old, though still sound, they may grow only about one twenty-fifth of an inch per year.

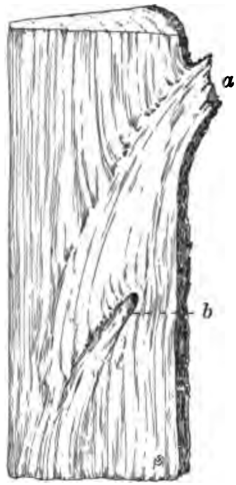


FIG. 46. Formation of knots due to branches. The figure gives part of a lengthwise section of a stick of birch wood

a, section of the base of a branch which persisted until the tree was felled; *b*, section of the base of a branch which died some years earlier and is now covered by several layers of younger wood

Would it be good policy to let beeches and maples remain long in the forest after they are one hundred years old before cutting for timber? Why?

65. Growing points. The extreme tip of the live stem or root of a dicotyledon consists of a more or less conical or cushion-shaped mass of tissue composed of thin-walled cells like those of the cambium layer. This portion of the stem or root is called the *growing point*. Every live twig and rootlet is tipped with a growing point, and it is by the rapid sub-division and consequent multiplication of these cells that the lengthening of the main stem and its divisions, and of every root, takes place.

All branches originate from growing points, which are usually developed along leaf-bearing portions of the stem, each one just above the point where a leaf is attached. In their earliest beginnings both leaves and rudimentary branches consist wholly of thin-walled cellular tissue. Fibrovascular bundles, connected with those of the underlying stem, soon appear in the branches and leaves as their development goes on.

As the branch lengthens, its wood cuts across the annual layers of the stem from which it grows, and the branch forms its own annual rings. Knots are not all due to the growth of branches, but most of them are, as may be seen from figure 46. If a knot-forming branch dies early, new wood forms over it and covers it up, as the figure shows; but if it continues to live as long as the main stem does, it gives rise to a knot that reaches to the outermost layer of wood in the stem.

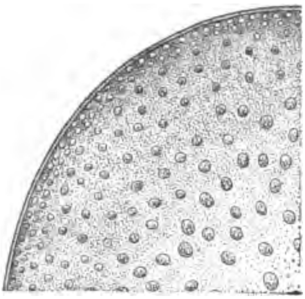


FIG. 47. One quarter of a cross section of a corn stem, showing the hard cortex and within it the soft pith, throughout which many fibrovascular bundles are irregularly scattered

In figure 46 which knot, *a* or *b*, would be the more likely to injure the timber?

66. Internal structure of the monocotyledonous stem. In the very young monocotyledonous stems of seedlings the fibrovascular bundles are constructed like those of dicotyledons. The wood elements are on the one side and the cortical elements on the other. In the full-grown stems of most monocotyledons the bundles have their vessels and other wood elements arranged in a hollow cylinder inclosing that part of the bundle which corresponds to the portion shown outside of the cambium ring in figure 42, *A*. In the adult monocotyledonous stem (when it is solid) the bundles occur scattered all through the pith, as shown in a section of asparagus or corn stem (fig. 47). No such complicated bark as that of woody dicotyledons is found in monocotyledons.

67. Growth in thickness of the monocotyledonous stem. The very young stems of monocotyledons may for a time increase considerably in diameter by the formation of new bundles within them. But in monocotyledons all the cambium becomes changed into other tissues, so that none is left, as it is in dicotyledons, to develop new tissue. In monocotyledons the bundles are said to be *closed*, while those of dicotyledons, in

which active cambium remains, are said to be *open.* The palms and similar monocotyledonous trees cannot form annual rings of wood. There are, however, a few tree-like monocotyledons in which the trunk continues for years to increase in thickness, and may reach great dimensions, but these trunks do not thicken in the same way as do the trunks of our familiar trees.

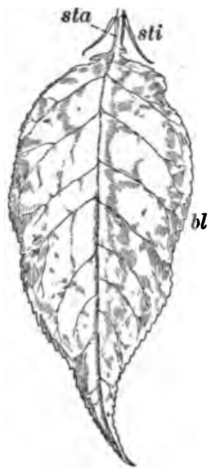


FIG. 48. A young leaf of wild black cherry

bl, blade, or expanded part; *sta*, leafstalk; *sti*, stipules, or appendages at the base of the leafstalk

Many of the woody monocotyledons are remarkable for the extraordinary length and slenderness of their stems. The rattans, for example, often climb for hundreds of feet among the tops of tropical forest trees.

68. The parts of the leaf. It already has been stated in section 11 that a leaf consists of petiole and blade. A few words may now be said about the external forms of ordinary leaves and the parts of which they consist.

At the base of the petiole many leaves bear a pair of appendages called *stipules* (figs. 48 and 49). In some leaves, as those of the pansy, these form an important part of the total leaf surface. Not infrequently, as in the black locust, the stipules have the form of thorns, one at each side of the base of the petiole.

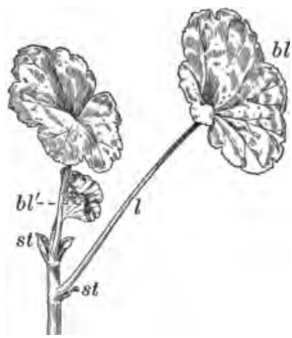


FIG. 49. Tip of a geranium (*Pelargonium*) shoot

bl, blade of a leaf; *bl'*, blade of a young leaf, only partly expanded from the naked bud; *l*, leafstalk; *st* stipules. Considerably reduced

In general the form of the leaf depends very much on the distribution of the groups of fibrovascular bundles known as *veins.* Most monocotyledons have

leaves with the veins running somewhat parallel to each other. Sometimes, as in the canna (fig. 50), the veins run both ways from a midrib, but oftener, as in corn and the other grasses, the veins run from the base to the tip of the leaf. This latter system of veining is most commonly found in long, narrow leaves. Most dicotyledons have net-veined leaves. These are of two types: those like the leaf of the willow, oak, and

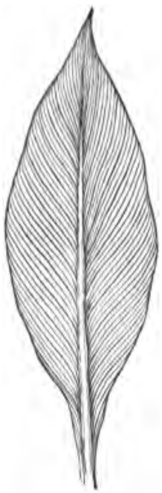


FIG. 50. Parallel-veined leaf of canna, veins running from midrib to margin

FIG. 51. An apple twig in the autumn

Alternate arrangement of leaves

peach, with the smaller veins running both ways from a midrib; and those like the geranium, hollyhock, and cucumber, with the veins radiating from the base of the leaf, like the sticks of a fan (fig. 49). Net-veined leaves with feather-like veining frequently have a length several times as great as their width, while those with fan-like veining are often roundish in their general outline. Whatever the shape of the leaf, the veining is so disposed that *a ready means of distribution throughout the leaf is offered to the water brought into it through*

the fibrovascular bundles connecting it with the stem. The importance of this is clear from what has already been said (sect. 37) about photosynthesis as a process of food-making in which the elements of water from the soil and of carbon dioxide from the air are brought together in the leaf to form sugar and starch.

FIG. 52. Top view of vertical shoot of syringa (*Philadelphus*)

The leaves are arranged in pairs, and each pair overlies the spaces between the pair immediately below it. One fourth natural size

Have the veins of the leaf other uses besides their function as conveyers of water? Explain.

69. Alternate and opposite arrangement of leaves. When a leafy apple twig (fig. 51) is compared with one of maple or box elder, it is evident that the former has its leaves arranged in a spiral order, while the latter bears its leaves in pairs. One leaf of each pair is on the opposite side of the twig from its mate, and a leaf of each pair covers the interval between the two leaves next above or the two leaves next below (fig. 52). Leaves borne in spirals are said to be *alternate*, and those in pairs, like maple leaves, are said to be *opposite*.

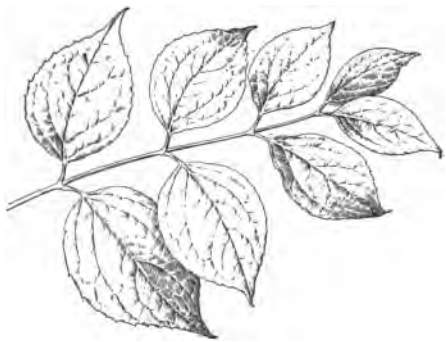


FIG. 53. Top view of a horizontal shoot from the shrub shown in figure 52

The leaves spring from the branch in the same order as do those of the vertical branch, but by a twisting of the leafstalks the blades are made to lie in a nearly horizontal position, and thus secure abundant illumination. One fourth natural size

The spiral arrangement is much the commoner, being characteristic of most herbs, most shrubs, and very many hard-wood and fruit trees. Some of the most familiar opposite-leaved

shrubs and trees, besides those already mentioned, are the lilacs, the ashes, the horse-chestnut, and the buckeyes. Many kinds of spirals occur, the simplest being that of indian corn, in which the leaves stand in two rows along the stem, the third directly above the first, the second above the fourth, and so on.

70. Importance of leaf arrangement. The photosynthetic work of ordinary leafy plants is run by sun power, or (to put it more technically) is due to the energy derived from the sun and acting on the green cells of the leaf. Clearly, therefore, it is usually as important for sugar- and starch-making that the leaf should catch all the sunlight it can get, as it is for rapid sailing that a sailboat should expose its sails as fairly as possible to the wind.[1] The student will find it well worth while to observe the arrangement of alternate leaves, which are so placed, both

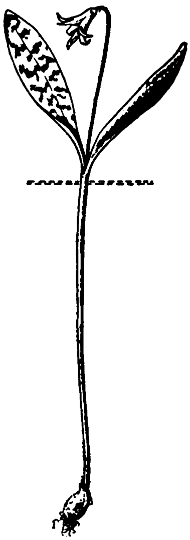


FIG. 54. Entire plant of dog-tooth violet (*Erythronium*)

Hardly any aërial stem appears, the flower stalk being sheathed by the leafstalks and arising from a deeply buried bulb. One fourth natural size

FIG. 55. Rosette of leaves of the common evening primrose, as seen at the end of the first year's growth of the plant

[1] Leaves just unfolding from the bud, some of those exposed to tropical suns, and certain others (sect. 51) are exceptions.

on vertical and on horizontal branches, that they lie flatways to the sun and do not overshadow each other. The way in which these results are secured in the case of opposite leaves is well shown in figures 39, 52, and 53.

71. Rosette plants. Some plants, such as the dandelion and the plantains, have their leaves spread out in the form of a

FIG. 56. Poison ivy, a root climber
Reduced

rosette at the top of an extremely short stem, which people usually suppose to be the crown of the root. Rosette-formers and some other kinds of plants (figs. 54 and 55) are therefore often incorrectly said to be stemless. During the first year of growth from the seed a good many *biennials*, like the common evening primrose (fig. 55), beets, carrots, and parsnips, form a more or less perfect rosette crowning a stout, fleshy root. The second year they produce a tall, leafy stem, then blossom and bear seeds. In rosette plants the leaf is usually

narrow at the base and wider at the tip, as in the evening primrose, so that nearly all the space between the leaves is filled in.

During which year of the life of a biennial is its principal work photosynthetic? During which year is it reproductive? Why are beets, carrots, parsnips, and salsify used as food at the end of the first season's growth?

FIG. 57. The wild frost grape, a typical tendril climber

This vine is climbing on an American elm. The height up to the branch *l* is about 60 feet, and the average circumference of the main vine, 3 feet. Redrawn and simplified from a photograph by Robert Ridgway

72. Leaf mosaics. Any combination of leaves (whether found in rosette plants or on longer stems) in which the space is very fully occupied, with few spaces between the leaves, is called a *leaf mosaic.* Walls covered with Japanese ivy furnish beautiful examples of leaf mosaics on a large scale, and many of our common house plants illustrate the same phenomenon. In any leaf mosaic many of the leaves occupy a very different position from that which they would have taken if borne on a vertical stem.

73. Climbing into the light. Many plants, of very diverse families, secure a better exposure of the leaves to light by climbing. The principal types of climbing plants are four in number: *scramblers*, like the common climbing roses; *root climbers*, like the poison ivy (fig. 56) and the English ivy (fig. 40); *twiners*, like the morning-glory; and *tendril climbers*, like the grapevine. The only way in which one can get a thorough knowledge of the behavior of climbers is to watch them throughout as much as possible of the growing season.

The development and mode of operation of tendrils is especially interesting (figs. 58 and 59). The tendril is either a leafless, thread-like branch, as in the grapevine, or a highly modified leaf or part of a leaf, as in the cucumber. When a living and active tendril comes into contact with any suitable

FIG. 58. Bur cucumber (*Sicyos*), a tendril climber

At *a*, *b*, *c*, *d*, *e*, and *f* successive stages in the history of tendrils are shown. The tendril, at first curved, becomes straighter, then curls up at the tip, and finally (after becoming attached to some object) coils itself into a close spiral and thus draws the plant with considerable force toward the sustaining object

support for the climber, this contact brings about more active growth on the exterior side of the tendril (that side which does not touch the foreign object). In this way the tendril is made to coil about the support. Soon after the tendril has become attached, the free portions are thrown into coils, and the shortening which results draws the stem of the climber closer to the support.

74. Excessive illumination. While the leaves of plants growing in the shade often suffer from lack of sunlight and are usually so arranged as to utilize most fully what light there is, it is possible for leaves in exposed situations to have too much light. It seems certain that the most powerful sunlight may injure the chloroplasts and therefore cripple the power of the leaf to do its work of photosynthesis.

FIG. 59. Virginia creeper (*Psedera*), a tendril climber

The tendrils are modified shoots. At *a* they are seen fastened to a twig and at *b* adhering strongly by means of their expanded, disk-like tips to the surface of a wall

Compass plants, such as the common prairie rosinweed (*Silphium*) and the prickly lettuce, have leaves somewhat erect, with edges directed nearly north and south, so that they secure good illumination during the cooler morning and evening hours but present the leaves nearly edgeways to the sun at noon. Many other plants maintain some or all of their leaves in a nearly vertical position, but with the edges not directed north and south. In the olive many leaves point almost vertically upward, while in the commonest species of *Eucalyptus* (fig. 60) the leaves hang vertically downward.

In a great number of trees the young leaves from recently opened buds stand erect or hang straight down. In one tropical species[1] the illumination received by these young drooping leaves is not more than one five hundredth as intense as that received by the most exposed of the mature leaves.

[1] *Amherstia nobilis*, from Burma.

75. Daily movements of leaves. Any one who walks through a clover field at dusk is likely to be struck with the peculiar pale appearance of the leaves, very different from the dark-green color which they have in full sunshine. This paleness is due to the fact that as the daylight fades the leaflets droop, as shown in figure 61, so that little except the under surfaces are seen. A large proportion of the plants of the Pea family and many other plants have leaves that take a special night position. Some leaves, as those of the bean and the black locust, have three positions — one at night, another in ordinary daylight, and a third in intense sunlight. The daylight position is usually almost horizontal; the position for brilliant sunlight is vertical. In the locust the change from vertical to horizontal occurs quickly enough to make it worth while to watch it coming on as the sun moves westward after noon and the leaves are left in the shade.

FIG. 60. Branch of *Eucalyptus*, with leaves hanging almost vertically downward

About one fourth natural size. After Bonnier and Sablon

In plants of the Pea family the daily leaf movements are brought about by means of a sensitive, cushion-like organ, the *pulvinus*, situated at the base of the leafstalk. It is easy to see the use of the horizontal and the vertical leaf position, but the importance of the night position is not so well understood.

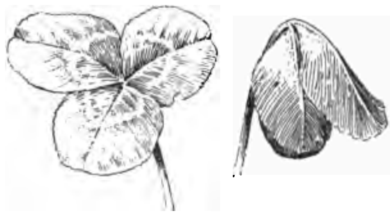


FIG. 61. A leaf of red clover

At the left, leaf by day; at the right, the same leaf at night. Natural size

76. Self-pruning of leaves and twigs. Many trees and shrubs begin to shed some of their leaves even in the spring, very soon after the leaves are well grown. Examples of this are

the lilacs, the syringa (*Philadelphus*), the cottonwood, the horse-chestnut, the box elder, and some lindens. Still more common is the loss of leaves during the summer, which may amount to 30 per cent of the total number of leaves. This leaf fall, coming long before the leaves are cast off in the autumn as a preparation for winter, affects chiefly the leaves inside the crown of the tree, which have such scanty light that they evidently cannot accomplish much photosynthesis.

FIG. 62. The pond lily, an aquatic with floating leaves and submerged stems

Leaves, twigs, and even larger branches which are not getting an adequate supply of light or of water are pruned away by the tree. Were it not for this, the dense growth in the interior of the tree top and along the trunk would soon render further branching mechanically impossible. What one sees on looking up along the trunk into the top of a large tree is mainly dead or dying branches, with few leaves. It is this self-pruning and that due to the shade of neighboring trees that makes the trunks free from knots and most valuable for timber in

trees grown in woodlands, where they stand moderately close together. In some trees — such as the so-called snap willows, the cottonwood, and the large-toothed aspen — live twigs fall very freely during windstorms and snowstorms, and when the tree is loaded with sleet. These twigs may be blown over crusted snow or floated along by brooks or rivers near by, and often lodge in spots where they take root and grow into new trees.

77. Leaves of water plants. Water plants with aërial leaves, like the cat-tails and pickerel weeds, are perhaps the commonest type. Others, like the pond lilies (fig. 62), have floating leaves, with only the upper surface exposed to the air. Still others, like some pondweeds, have all their leaves submerged. There are only a few common plants which have two types of leaf, like the water crowfoot (fig. 63), one set growing wholly in the air and the other set wholly under water.

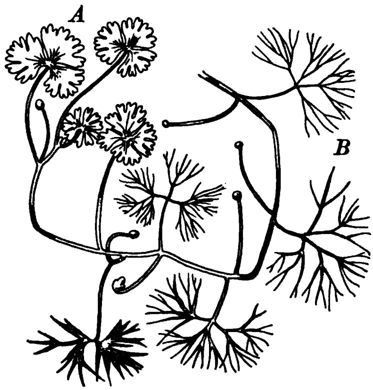


FIG. 63. A shoot of water crowfoot

A, air leaves; *B*, thread-like water leaves. After Askenasy

Floating leaves have stomata only on the upper surface; on the lower surface they could serve no useful purpose. Submerged leaves often have the thread-like form shown in figure 63. This form renders them much less liable to injury from waves or currents of water, and also allows the freest exposure of the whole leaf surface to the surrounding water. This offers the best possible opportunity for exchange of gases between the water in which they are dissolved and the interior of the leaf.

78. Size and shape of leaves in relation to water supply. Plants which grow in earth (that is, neither aquatics nor air plants) often show a decided relation between the abundance of the water supply and the amount of leaf surface. Those

kinds which usually grow in very damp soil or in swamps, such as the jack-in-the-pulpit, skunk cabbage, white hellebore, papaw, and some magnolias, are frequently large-leaved plants.

Many plants which grow in extremely dry soils, or in regions where the summer rainfall is scanty or altogether lacking, are characterized by small leaves, often awl-shaped or thread-like. Few familiar examples of such plants with highly reduced leaf surface are to be found among the wild plants of the northern United States.

FIG. 64. The crowberry

This plant has minute leaves with their margins rolled under. It thrives in dry, exposed situations. About one half natural size

FIG. 65. A fleshy-leaved plant (*Mesembryanthemum*) with much water stored in the stiff, clustered leaves

After De Candolle

The crowberry (fig. 64) is one good instance of the kind, and a few weeds of the Pink family, some St.-John's-worts, and some little spurges are other examples. The heather (*Erica*), often cultivated in greenhouses, is an excellent instance of minute, awl-shaped leaves.

Thick, fleshy leaves (fig. 65) are common in plants of desert or semi-desert regions. Some of these leaves are almost cylindrical; others are tongue-shaped; others, like those of the century plant, are thick and broad at the base and taper to a spiny tip. All fleshy, or *succulent*, leaves hold much stored water for use in seasons of drought.

79. Structure of leaves in relation to water supply. Leaves of plants which grow in very moist earth usually have a moderately thin epidermis[1] and are of a rather loose interior structure, with abundant air spaces — even more than are shown in figure 26.

The leaves of plants which usually grow in places where they are sometimes in great danger of dying for lack of water commonly have a thick, nearly moisture-proof epidermis and closely packed cells in the interior of the leaf. This insures slow evaporation of whatever water is carried into the leaf, since the thick epidermis prevents rapid drying up of the cells near the exterior, and the scanty air spaces render the circulation of dry air coming into the leaf slow and difficult. Such leaves are often densely covered with hairs, especially on the lower surface, and this coating of hair has been found greatly to hinder the escape of moisture through the stomata.

FIG. 66. The giant cactus

This specimen is about 40 feet high. The holes seen in one of the stems are birds' nests. Photograph by the Desert Botanical Laboratory of the Carnegie Institution

[1] It is not necessary to discuss here the marsh plants and halophytes treated in works on the ecology of plants.

Frequently each stoma is at the bottom of a depression, or pit, in the epidermis, and is thus somewhat protected from drying currents of air.

80. Xerophytes. Plants like the cactus (fig. 66), the desert *Pelargonium* (fig. 20), the crowberry (fig. 64), and a multitude of others (many of them not marked by any such peculiarities of form and structure as these are), which can resist conditions of extreme drought, are called *xerophytes*. The only way in which one can get a good idea of the difference between xerophytes and ordinary plants, or *mesophytes*, in their power to endure a combination of high temperature and scanty water supply is to compare their behavior under conditions of drought. A potted plant such as a cactus or a houseleek for a representative xerophyte, and a young bean plant or mustard plant for a typical mesophyte, if left unwatered, will afford material for a highly profitable comparison of types.

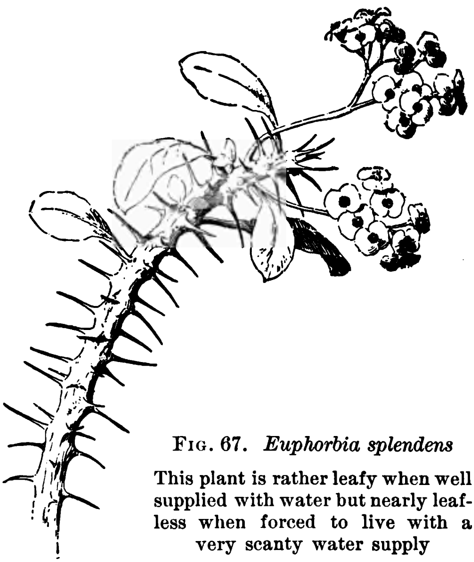


FIG. 67. *Euphorbia splendens*

This plant is rather leafy when well supplied with water but nearly leafless when forced to live with a very scanty water supply

Are any xerophytes of economic value? any mesophytes? any water or marsh plants? Give as many examples as possible.

81. Advantage of shedding leaves. When the soil temperature is nearly at the freezing point, most plants are unable to absorb much water by their roots. It is probably owing mainly to this fact that our ordinary *winter deciduous* trees have their habit of shedding their leaves at the approach of winter. If

their actively transpiring leaves were to remain at work while the ground was almost or quite frozen, the tree would suffer a fatal loss of water.

It has been found that the larch (which sheds its leaves) is more resistant to such conditions than are most of the evergreen conifers, although the latter have leaves of a highly xerophytic type. In a rainless summer some shrubs retain or shed their leaves in proportion to the amount of soil moisture with which they are supplied. The *Euphorbia splendens* (fig. 67) is a commonly cultivated plant which well illustrates this capacity to adjust the amount of leaf surface to a varying moisture supply. In regions like Southern California and the coast of the Mediterranean, where the long, hot summers are nearly rainless, some trees and many shrubs are *summer deciduous*, losing almost or quite all of their leaves at the beginning of summer. Twigs in this leafless summer condition have been found to lose in a given time only about one thirty-sixth as much water as they do when in full leaf.

The shedding of the leaf is a somewhat complicated process; a waterproof layer of tissue is formed at the base of the leaf-stalk, and this cuts the leaf off from communication with the stem. Before this layer is formed, the plant food in the leaf has often been conveyed into other parts of the plant, so that when the leaf falls, it takes with it little of value.

PROBLEMS

1. Show that the roots, stem, and leaves of ordinary trees coöperate to do the work of food-making.

2. Why is it that trees which are left standing after their forest neighbors have been cut away are more liable to injury from windstorms than are those which have always grown in the open?

3. Discuss the various ways of climbing, and show which are generally the most effective in securing a good light supply under great difficulties.

4. From what you have seen, does it seem probable that the different kinds of plants in a piece of woodland all require about the same intensity of light? Discuss this matter, giving examples.

5. Would you expect to find any kind of compass plants in woodlands? Why?

6. Why do most aquatic flowering plants have leaves that are exposed to the air, rather than submerged leaves?

7. Why are trees of the moist tropical regions usually evergreen?

8. May a shrub or a tree be deciduous or evergreen, according to circumstances? Give examples.

9. If you wanted to make a cactus plant produce leaves, how would you treat it? Why?

10. If an aquatic plant were transplanted into desert soil and an extreme xerophyte into a shady swamp, what appearances would in each case soon show that the plant was dying?

11. What mesophytes do you know that can grow under a very wide range of conditions as regards light and moisture? Compare, with regard to their tolerance of drought, some common plants important in agriculture.

CHAPTER VI

SPECIAL FUNCTIONS AND FORMS OF STEMS

82. Stems not always for the support of leaves. In Chapter V considerable space was given to explanations of some of the ways in which stems serve to support leaves in advantageous positions for photosynthetic work. This is not, however, by any means the only function of the stem or portions of the stem. Something was said in Chapter IV about the importance of food storage in stems, and something in section 56 about their work of photosynthesis. Some other important things done by whole stems, or by more or less highly specialized portions of them, will be discussed in the present chapter.

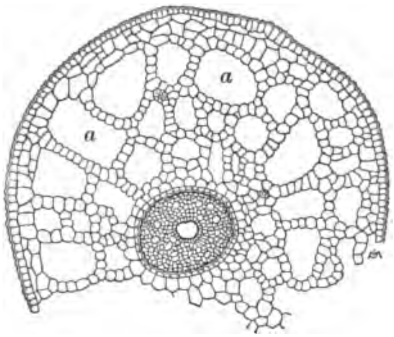


FIG. 68. Cross section of stem of pondweed (*Potamogeton*), showing air passages *a*, much magnified. After Green

83. Storage of air or water in the stem. It seldom happens that the same plant would be benefited by storing both air and water abundantly in its roots or stems; but marsh and water plants may evidently be much aided in their respiration by holding a good deal of air inside the plant body. In some such plants the air passages and air cavities form a complex system, which extends all the way from the stomata to the tips of the roots. A section across the stem of any of the common pondweeds (*Potamogeton*) (fig. 68) shows clearly how large and abundant its air passages are.

Desert plants, or those which for any reason may often be exposed to intensely hot, dry air, are safer without large air cavities anywhere in the interior of the plant, but stored water is of the greatest use to such plants, and it may be found in the roots (fig. 20), in the stem (fig. 66), or in the leaves (fig. 65).

84. Characteristics of underground stems. The popular notion of a stem includes the idea that it is an aërial part of the plant. It is easier to recognize as roots such structures as the aërial roots of corn and of poison ivy than it is to recognize as stems the thickened underground portions of iris, jack-in-the-pulpit, dragon-root, trillium, or potato. Frequently, like aërial stems, underground stems are divided into nodes and internodes; many of them bear scales which represent leaves, and in the axils of these scales they produce

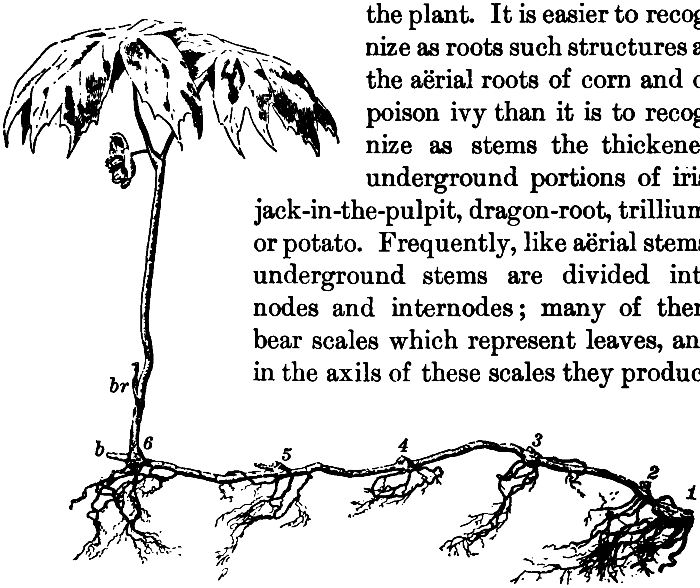


FIG. 69. A May-apple plant, showing the history of the rootstock

1 is the oldest surviving portion of the rootstock; *2* is a year younger; *3* a year younger than *2*, and so on. At each figure the cluster of roots marks the position of the base of the upright stem for that year, as is shown at *6*. *b*, bud for the new year's growth; *br*, bract at the base of the present stem. One sixth natural size

buds. Such buds are well shown in the underground stems of some grasses. Dicotyledonous underground stems usually have distinct bark, wood, and pith; most dicotyledonous roots do not have pith, though some do.

Some of the principal forms of underground stems have for convenience been given special names. The elongated forms,

like that of the May apple (fig. 69), the mints, couch grass, and many other plants, and some stouter kinds, like that of the trillium and Solomon's-seal, are known as *rootstocks*, or *rhizomes*. The very short shoots with disk-like stems and a covering of scales, or of coatings formed by thickened bases of leaves (familiar in some lilies, the tulip, and the onion), are called *bulbs*. Much like bulbs, except that the stem is more developed and that the scales are almost lacking, are *tubers*, like those of the Jerusalem artichoke, the potato, and the crocus.[1] The potato is a particularly good tuber for study, as it has well-defined nodes and internodes; the buds (eyes) are arranged in a distinctly spiral manner and are borne in the axils of little scales which represent leaves, and not infrequently the tuber is considerably branched.

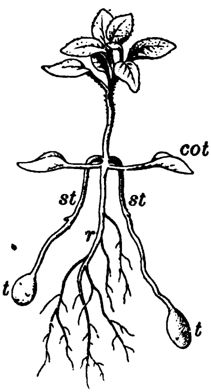


FIG. 70. A potato seedling ten weeks old

cot, cotyledons; *st*, tuber-bearing underground stems; *t*, very small tubers; *r*, root. Three fourths natural size. After Percival

85. Reproduction by portions of the stem. Some plants naturally reproduce themselves mainly by more or less specialized portions of the stem, and in a cultivated state many others are made to do so. There are numerous kinds, such as the potato, the strawberry, the banana, and most lilies, that are almost always propagated by some sort of stem or shoot.

Many plants bear small aërial bulbs or tubers on some portion of the stem and are commonly reproduced by these. Familiar examples among cultivated plants are the onion and the tiger lily. The bulblets known as onion sets are for sale at every seed store, and in some parts of the country are almost exclusively planted by onion growers, while in other sections the seed is more generally planted. The black bulblets of the tiger lily

[1] Such very short underground stems as that of the jack-in-the-pulpit and the crocus are often called *corms*.

Fig. 71. A potato plant grown from the tuber, ten weeks old

o, old tuber; *s*, stems on which young tubers are forming. One sixth natural size. The total space occupied by this plant is much more than two hundred times that occupied by the seedling plant of the same age (see fig. 70)

are borne in considerable numbers along the stem, in the leaf axils, and may be found on the ground, rooting, in the late autumn and the following spring. Some of our common wild plants, including certain ferns, are propagated by bulblets.

Underground stems of various kinds are so common as means of reproduction that only a very few of them need be mentioned. Some of the worst weeds are those which have running rootstocks, like the nut grass (*Cyperus*), which produces many little tubers, each of which may grow into a new plant, and the couch grass (Chapter XX) and Canada thistle, which may be cut up by the hoe and produce a new plant from every node. Among cultivated plants a great number of the earliest blooming herbaceous kinds, such as squills, hyacinths, tulips, crocuses, and snowdrops, are grown from bulbs or other forms of underground stem. The commonest of all instances of propagation by this kind of stem is that of the potato (figs. 70 and 71), which is never grown from seed except for the production of new varieties. As every farmer and market gardener knows, each potato will produce as many new plants as it has buds, or eyes,

FIG. 72. A black raspberry plant reproducing by a natural stolon

At *A*, the original root system; at *B*, a newly formed root system with a young shoot *sh*. Much reduced and somewhat diagrammatic. The arch is really much flatter and the dying portion of the stem, *aa'*, proportionally five or ten times as long as here shown

though it is better not to cut the potato into too small pieces for propagation, or the plants will grow slowly at first.

Why are potatoes almost always grown from the tuber rather than from seed? Why are plants of the Lily family grown from bulbs?

FIG. 73. A willow cutting

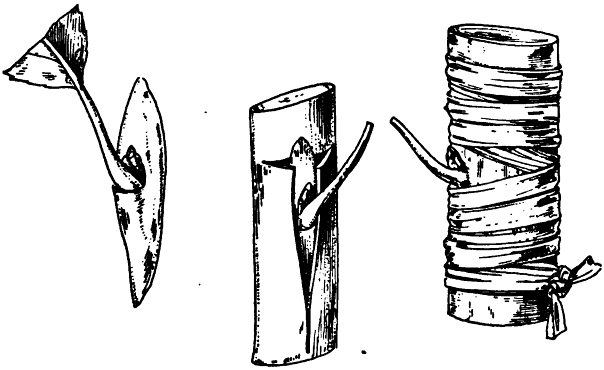
The roots are a little more than two months old. Somewhat reduced

86. Stolons, runners, and cuttings. Some plants, as the black raspberry (fig. 72), are naturally propagated by recurved branches which root wherever they touch the earth. Such rooting branches are called *stolons*. An artificial modification of this process (called *layering*), sometimes made use of in growing apples, pears, plums, and quinces, consists in bending down branches and covering portions of them with earth until they become well rooted.

Runners, like those of the strawberry, are very slender, nearly leafless, stolons.

Cuttings are twigs or branches cut off, set in the earth, and kept there until they become well rooted (fig. 73). Numerous woody plants, such as willows, grapevines, currant bushes, gooseberry bushes, and geraniums, and some herbaceous plants, such as the hopvine and the Wandering Jew, are usually grown from cuttings. Many others, such as the French marigold and the garden portulaca, not usually thus grown, may be readily propagated by cuttings. In the case of woody plants the cutting should be taken from well-matured twigs of the previous season. To avoid wilting, leafy cuttings are often kept covered for a time with a tumbler or bell glass.

87. Budding and grafting. The process of *budding* consists of detaching an uninjured bud from the stem of one plant and inserting it under the bark of the stem of another plant (fig. 74). Peaches and cherries are familiar examples of trees commonly propagated by budding. The operation should be performed at a season when the cambium layer is active, so that the transplanted bud will at once unite with the wood of



A *B* *C*

FIG. 74. Propagation by budding

A, a bud cut from a tree of the desired variety, with a piece of the underlying bark; *B*, the bud inserted in a T-shaped slit in the bark of the stock; *C*, the same with the bark bound in place by strips of raffia (a fibrous material obtained from the leaves of the raffia palm). Modified after Percival

the stem into which it is set. In the case of peaches, the young seedling trees grown from seeds planted the same spring are budded in June or September. Those budded late do not grow much until the next season, but then make rapid progress. As the top of the seedling is cut off not far above the bud, all further growth of the shoot partakes of the quality of the bud, and the fruit borne by the tree, when it is large enough to bear, will be of the kind that is characteristic of the tree from which the bud was taken.

Grafting is removing a piece of stem, with its buds, from one plant and inserting it into a portion of stem of another

living plant so that the cambium layer of each will be in contact with that of the other (fig. 75). The plant into which the stem is inserted is called the ***stock***, and the portion of shoot which is set into the stock is called the ***scion***, or ***graft***. There are many kinds of woody plants which may readily be grafted, but the process is of practical importance mainly for the grower of apples and pears. Various plans are adopted in different fruit-growing regions. One of the commonest methods for the propagation of apples is *root grafting*. Seedling trees a year old are dug in the autumn and the roots grafted with one-year-old scions of desired varieties of apple trees, each cut to the length of about six inches. The grafted roots, wound about the joined surfaces with waxed cord, are packed in sand in a cool and not too dry cellar and left until spring. By that time the cambium layers of root and scion have united and the roots are ready to plant. *Tongue grafting* is practiced in the spring either with young seedlings or with twigs of larger trees (fig. 75). *Top grafting* consists in cutting off limbs one or two inches in diameter, splitting for a short distance the portion remaining attached to the tree, and inserting at each part of the split, where it crosses the cut surface, a small scion, and then completely covering all exposed parts with grafting wax. Root grafting has the advantage of resulting in a tree with trunk and branches wholly of the desired variety of apple. Tongue grafting of small branches does not interrupt the growth of the tree and is done with very little trouble. Top grafting is mainly resorted to in order to renew old trees that are not bearing the desired variety of apple.

FIG. 75. Grafting

At the left, scion and stock are shown ready to be united; at the right, they are joined and ready to be covered with grafting wax. After Percival

The student should notice that, while budding and grafting are described as modes of vegetative reproduction, *their object is not to increase the number of shrubs or trees in the garden or orchard.* It is rather a means of propagating the desired kind of plant with certainty — for example, to secure a certain variety of fruit. This cannot be done merely by growing seedling trees, since every seedling grown from any valuable kind of apple or pear may differ from all the others of the same lot (fig. 163), and not one of them be worth cultivating.

Grafting often succeeds on plants of different species,[1] as the peach on the plum, the apple on the pear, and the pear on the quince. Sometimes it succeeds between different genera [1] of the same family,[1] as the tomato on the potato.

Many technical details best learned from a practical horticulturist are necessary in order to bud or graft successfully.

PROBLEMS

1. What common feature would you be likely to find in the structure of the stems of pickerel weeds, cat-tails, and rushes, and in the leafstalks of pond lilies and lotuses?

2. Large cacti in the deserts of the southwestern United States and Mexico are often cut open in order that their sap may be used for drinking water. Where did the plant get so much water? How could it have used the water?

3. What common garden plants are reproduced by bulbs? Can any of these be grown from seeds?

4. Do most kinds of plants grown from bulbs bloom early or late? To what two kinds of climate are such plants suited? Give examples, among both wild and cultivated plants, to illustrate your answer.

5. Could more than one kind of scion be top-grafted on a single stock? Why do top-grafted trees, after they come into bearing, require more careful pruning than ungrafted trees? What kind of fruit will be borne by shoots that arise below a graft?

6. Do bulbs planted in autumn freeze in winter? What are the best methods and times for the outdoor planting of bulbs in your locality? Should different plans be used for different kinds of bulbs?

[1] For the definition of the terms *species*, *genus*, and *family*, see Chapter XIII.

CHAPTER VII

BUDS AND BRANCHES

88. Occurrence of buds. If we look at the live branches of any shrub or tree during the winter, many buds will be found along their sides, and usually each twig is tipped with a bud. Most people are aware of these facts, but they have not generally observed that the formation of these buds began rather early in the summer. It is not usual, among those who are not botanists, to speak of the buds of herbs, such as beans, peas, tomatoes, and cucumbers; and yet such plants are well provided with buds, only they are inconspicuous and often nearly hidden by the young leaves at the tips of the shoots.

FIG. 76. Opening leaf bud of rose

a, *b*, *c*, and *d* show stages of transition between bud scales and fully developed leaves. After Payer

To be accurate we must classify buds into scaly *winter buds* (or *resting buds*) and *naked buds*. The latter occur not only on all herbs (fig. 49) but also on the shrubs and forest trees of hot countries.

Generally speaking, scaly buds occur in woody plants which grow in cold or temperate climates, where such buds are well suited to resist the sudden winter changes from heat to cold, and the reverse. Some of our common trees and shrubs have

buds which are only slightly protected by scales, but these buds are usually small and often more or less hidden under the bark, as in the syringa (*Philadelphus*) and the thorny honey locust (*Gleditsia*).

89. Buds become shoots. If we watch the opening and subsequent growth of a bud (figs. 76, 83, and 84), we shall find that sometimes it develops into a leafy shoot; that is, it forms the beginning of a new twig or lengthens out the twig, branch, or main stem at the tip of which it was formed. Sometimes it develops into a flower or a cluster of flowers. Sometimes it produces both leaves and flowers. Buds, then, are classified, according to the results of their development, into *leaf buds*, *flower buds*, and *mixed buds*. And since a flower (as we shall see in Chapter IX) is only a peculiar kind of shoot specialized for seed production, we may define a bud as an *undeveloped shoot.*

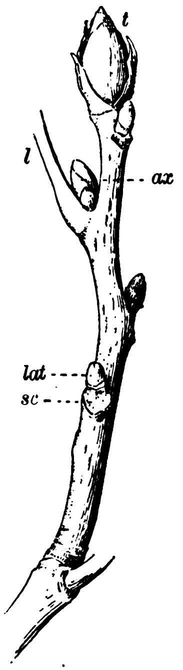


FIG. 77. Twig of hickory in winter condition

sc, scar of last year's leaf; *lat*, a lateral bud; *l*, a last year's leafstalk; *ax*, a lateral bud in the axil of the leafstalk; *t*, terminal bud. Reduced

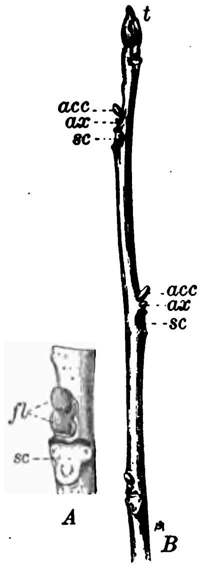


FIG. 78. Twigs of butternut, with accessory buds, in winter condition

A, part of a twig, near a leaf scar, about natural size; *B*, tip of another twig, slightly reduced; *acc*, accessory bud; *ax*, axillary bud; *sc*, leaf scar; *t*, terminal bud. Note the unequal size of the buds in *B*, and the difference in shape between the axillary and terminal buds in *B* (all leaf buds) and the two egg-shaped flower buds, *fl*, in *A*

90. Position of buds. Buds are either *terminal* (growing from the tip of the stem) or *lateral* (growing from its side).

The plumule (fig. 141) is the first terminal bud of the young seedling. Commonly the terminal bud is stronger than any of the lateral ones, and makes more rapid growth than they do.

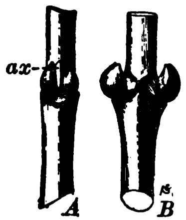


FIG. 79. Accessory buds of box elder

A, face view of a single group, with axillary bud, *ax*, between accessory buds; *B*, profile view of two opposite groups

Lateral buds are usually *axillary;* that is, they arise from the axil, or angle formed by the leaf with the stem, as shown in figure 77, *ax*. Many plants also produce *accessory buds*, that is, buds a little outside of the leaf axil, which may either stand above the axillary bud, as in the butternut (fig. 78), or on either side of it, as in the box elder (fig. 79).

Adventitious buds are those which spring, without any definite order, from roots, stems, or leaves. These are often of great value in propagating plants by means of cuttings or layers.

91. Bud position and branching; form of trees. Plants with alternate leaves bear alternate buds, and those with opposite leaves bear opposite buds. If the buds develop into branches, their arrangement will of course follow the plan of the leaf arrangement. Figures 80 and 81 show the results of one year's growth of twigs from alternate and from opposite buds. Sometimes (fig. 81) the branch is terminated by a flower cluster. In this

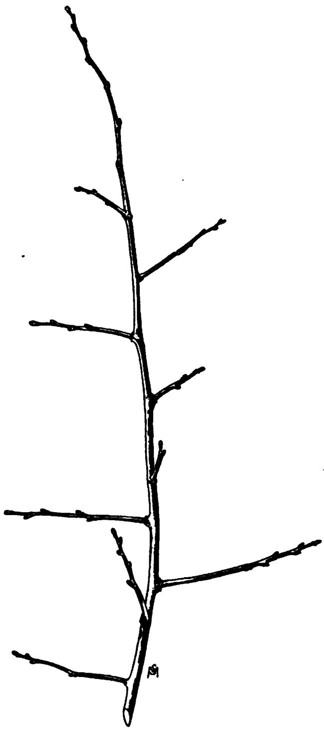


FIG. 80. Alternate branching in seedling tree of cultivated crab apple

case it cannot grow straight on from the tip the next year, but one of the twigs a little farther back will be rapidly developed and will serve to prolong the main branch.

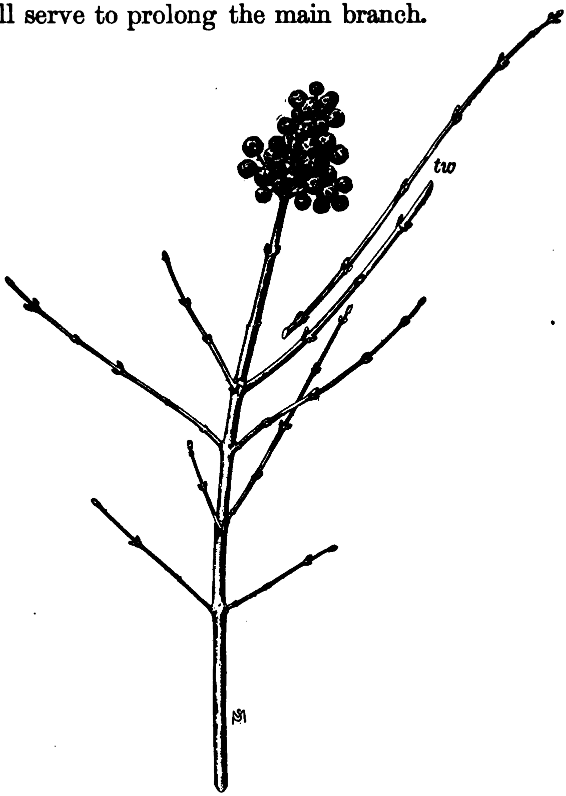


FIG. 81. Opposite branching in privet

The branch is shown as it appeared in March. The growth of the year terminated in a flower cluster, followed by fruit. Since no terminal bud was formed, the continuation of the main branch during the next season would have been by the strong growth of the twig *tw*

If the terminal bud of the main stem continues year after year to be the strongest, the general form of the tree will be somewhat conical, as are larches and spruces; but if some branches grow in length as fast as the main trunk, the tree will become round-topped and spreading, like an apple tree.

92. Competition among buds and branches. Seen from a little distance the top of a tree usually appears like a somewhat conical or hemispherical mass of leafy branches, but on looking along the trunk up into the tree top one sees that the interior of the crown is hollow, nearly destitute of leaves, and with few live twigs on the trunk (except near its upper end) and few on or near the bases of the branches. A very large proportion of all the much-shaded twigs that might be developed into branches during the growth of a tree are actually killed by light-starvation. They cannot do photosynthetic work and are therefore without food.

FIG. 82. A pollarded willow sending out many slender twigs from buds which would not have grown if the main branches had not been cut away

Cutting off the top or the main branches of many kinds of trees (*pollarding*) causes buds along the trunk and larger branches to develop into slender twigs, used for withes and for basket-making (fig. 82).

93. Fruit spurs. A *fruit spur* is a short fruit-bearing twig borne on the side of a branch (figs. 83 and 84). Apple, pear, plum, and cherry trees afford capital examples of the production of fruit spurs. At the tip of the spur a flower bud (or a mixed bud) is borne, and this usually develops into a cluster of flowers, one or more of which, under favorable conditions for growth, may mature into fruit. In the apple and the pear (fig. 84), although the

flower bud contains a good many blossoms, only one fruit is generally produced from each bud. In cherries a single bud produces a cluster of fruits. Why?

FIG. 83. Development of leaf bud of pear

A, a leaf bud of pear in autumn; *B*, a leafy shoot derived from *A*, as seen in the middle of the following summer, with flower bud at tip; *C*, the fruit spur *B* as it appears in autumn, after the falling of the leaves

FIG. 84. Fruit bud of pear (same as *C* of fig. 83), showing its development

A, opening in spring; *B*, later, developing flowers and leaves; *C*, later still — only one flower has produced a fruit, the rest having fallen off without maturing, and below is a lateral mixed bud which will continue the spur next year

If the terminal bud of the spur contains leaves as well as flowers, a leaf bud is likely to grow in the axil of one of the leaves and thus provide for the growth of the spur during another year. This process may go on for a good many years.

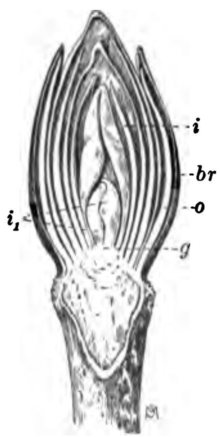


FIG. 85. A lengthwise section of bud of thorn tree (*Cratægus*)

br, brown outer bud scales; *o*, pale bud scale; *i*, innermost rudimentary leaves; *g*, growing point at apex of twig, consisting of cells in a condition to sub-divide and multiply rapidly at the beginning of the growing season. Somewhat magnified

Evidently, when the spur produces a terminal bud containing flowers, it cannot grow straight ahead but must turn aside somewhat. A little study of the age of fruit spurs, made by cutting across them and counting the rings of growth, shows that they increase in length very slowly. This must be the case, since much of the plant food used by the spur is expended in producing the flowers and fruit. The flower scars on an old fruit spur are not all alike, some being much larger than others. This is because the smaller ones mark the places where flowers were borne but no full-grown fruit was matured, while the ones that bore successful fruit are larger and more sharply defined.

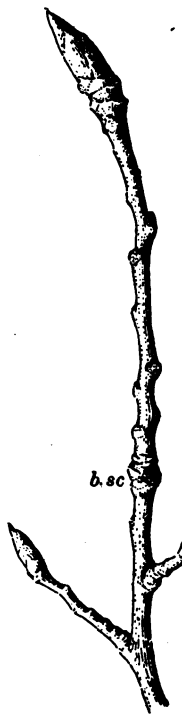


FIG. 86. Twig of cottonwood with buds in winter condition

b.sc, bud-scale scars. Two thirds natural size

What would be the effect on the growth of a young tree if all the fruit spurs or buds that produce them were pruned away year after year?

94. Structure of winter buds. The scaly buds of our common trees and shrubs are readily picked to pieces as soon as they begin to swell in early spring, but it is easier to distinguish the parts of which they are composed by watching the opening process from the very beginning. Sections of buds, if carefully made, show very clearly the relations of the parts (fig. 85). In a leaf bud there are, on the outside, the leathery bud scales; inside of these are rudimentary leaves;

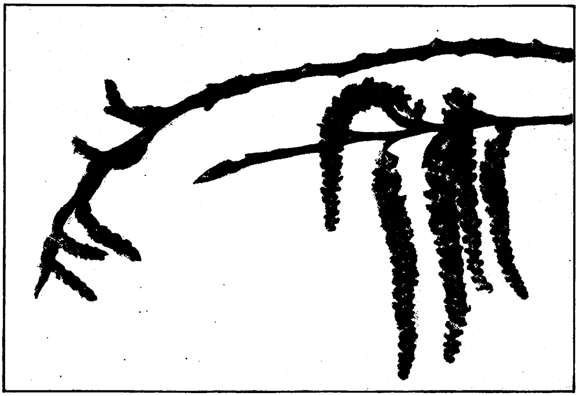


FIG. 87. Cottonwood twigs, April 15

The flower buds on the lower twig (developing into catkins) are fully open, but the leaf buds are still closed. Reduced

and within and below the leaves is a central axis tipped with a *growing point* composed of rudimentary cells capable of rapid division and growth.

The scales which cover buds are often the dwarfed and otherwise modified leaves or leafstalks, as is well shown in some buckeyes and in roses in which the opening buds present a series of gradations between mere scales and foliage leaves (fig. 76). In other cases, as in oaks, beeches, lindens, and magnolias, the scales represent the appendages (*stipules*) found at the bases of many leaves. Frequently bud scales are covered with a dense layer of hairs or down, and sometimes, as in

some of the poplars and the horse-chestnut, they are cemented together by a resinous varnish. These coatings of somewhat cold-proof and water-proof materials increase the value of the scales as a protection against sudden changes in the weather during the colder months.

In mixed buds the flowers are usually inclosed by the leaves and develop first (fig. 84, *B*).

95. Opening of buds. Long before winter buds are ready to open they usually begin to swell, and this increase in size may continue through several months. The actual opening sometimes goes on rather rapidly, the scales being shed in such numbers as almost to carpet the ground, as they do, for example, in beech woods. The rudimentary flowers are generally much more sensitive to cold than the young leaves are, as every fruit grower knows. Flower buds are not so likely to be injured by continued cold weather as by severe frosts coming after the buds are partially open. On this account the growing of fruits which are not very hardy (such as the peach) is safest in those parts of the Northern states where the spring comes on late and without interruptions. Parts of the eastern shore of Lake Michigan are for this reason well adapted to peach growing. Damage to buds often comes rather from sudden changes than from extremely low temperatures.

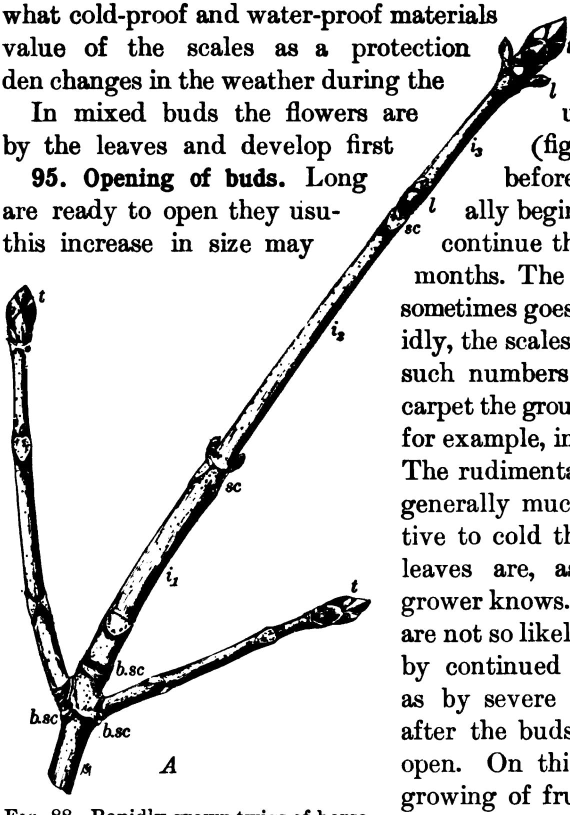


FIG. 88. Rapidly grown twigs of horse-chestnut in winter condition

b.sc, bud-scale scars; i_1, i_2, i_3, internodes; *l*, lateral buds; *t*, terminal buds; *sc*, leaf scars. The portion i_1–i_3 and the large terminal bud grew during the preceding spring and summer. The opposite lateral twigs are of the same age as the portion i_1–i_3. One third natural size

96. The record borne by the twig. In most cases the twig bears upon its surface and in its rings of wood a fairly complete record of the most important events of its life (fig. 90). Some of the markings on the surface of a twig which enable us to make out its history are (1) bud-scale scars (from leaf buds), (2) fruit scars, (3) leaf scars. Other markings are found which tell less of the life history of the twig than those just enumerated, but which should also be considered, namely, (4) lenticels.

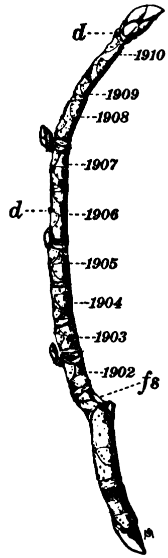


FIG. 89. A slowly grown twig of horse-chestnut in winter condition

d, dormant buds; *fs*, flower-cluster scar. The internodes are numbered in succession (beginning at the bottom) with the respective years during which they were formed. One third natural size

The bud-scale scars, as the name implies, are the markings (figs. 86 and 88, *b. sc*) left by the falling of the scales when the bud opened. Plants like geraniums, with naked buds, do not show such scars. As the twig or branch in most cases is prolonged by the growth, spring after spring, of its terminal bud, each ring of scars marks the beginning of a new season's growth. In many trees it is easy to determine the age of twigs or branches by counting the number of such rings (fig. 89). The distance between the rings of scars depends upon the rate of lengthwise growth of the shoot; this varies all the way from a fraction of an inch to ten feet or more per year.

1. How many times greater was the rate of growth of the central twig in figure 88 than the average yearly rate of figure 89?

2. What was the cause of this rapid growth? (Examine a horse-chestnut tree.)

3. If the twig in figure 89 grew unequally in different years, what is a probable cause of the fact?

4. How did the leaves of figure 88 compare in size with those of figure 89? Why?

5. Which bud of each year's growth is usually strongest?

6. How many wood rings would a cross section of figure 88 show at i_1? at i_2? at i_3? Why would these rings differ in size?

7. What would have been the effect upon the wood rings of figure 88 of pulling off most of the leaves above *b. sc* as fast as they appeared?

97. The record; fruit scars. Fruit scars of the same species are often quite unequal in size, the smaller ones marking the positions of unsuccessful fruits and the larger ones of fruits which grew to maturity. Sometimes in mixed buds the young flowers may be destroyed by frost as the bud opens, and in that case it develops much like an ordinary leaf bud, leaving no fruit scar.

In order to learn just the course which a bud follows during its development throughout a year or more, it should be marked by tying a bit of twine or winding a bit of fine copper wire very loosely just above or below it. Sketches like figures 83 and 84 should then be made and notes taken from time to time, whenever decided epochs in the history of the bud occur.

98. The record; leaf scars. Among the most prominent markings on a twig several years old are the roundish, or horseshoe-shaped, areas known as leaf scars (figs. 77 and 78, *sc* and 90, *sc*). These mark the positions where (at the base of each leafstalk) a waterproof layer was formed when the leaf was shed (sect. 81). Some of the things which can be learned from the study of leaf scars are the number, position, and arrangement of leaves on the shoot for several years back, the relative sizes of the leaves, and the mode of bud-bearing of the species studied — that is, whether there were accessory buds or whether the buds were all axillary. On careful examination of any large leaf scar, as that of the ailanthus, the horse-chestnut, or the coffee bean, it is seen to be dotted with a considerable number of minute projections. These mark the course of the fibrovascular bundles from

the leaf into the stem. In dicotyledons there are usually about as many such dots on the scar as there were principal veins in the leaf or leaflets of a compound leaf. Why?

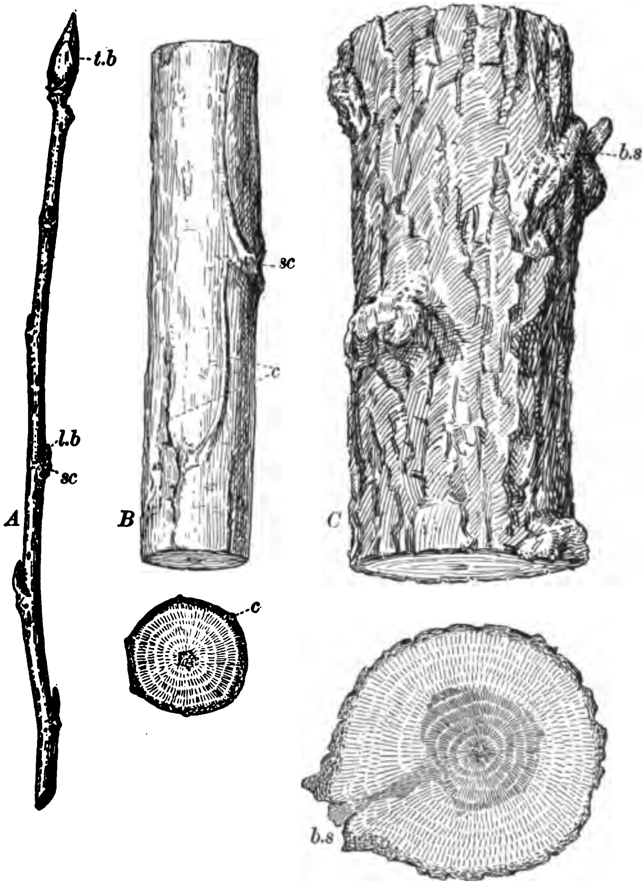


Fig. 90. Development of bark on cottonwood branches

A, young twig showing terminal bud *t.b*, leaf buds *l.b*, and leaf scars *l.s*, the bark being almost smooth except where lenticels appear; *B*, an older branch in longitudinal and transverse view, showing the bark *c* as it begins to be broken and ridged, and the leaf scar *l.s*; *C*, still older branch, showing the bark after it has become decidedly ridged, and also a branch scar *b.s*.

In tree-like monocotyledons the leaves are not shed as they are by the common trees of temperate climates. Frequently the leaves persist for years but finally decay and leave the trunk of the tree covered with a rough coating formed by the persistent bases of the leafstalks, as is the case with the date palm and many other kinds of palms.

99. Lenticels. Along the twigs and younger branches of most trees and shrubs there are found many dots or larger areas of rough, spongy bark. These are called *lenticels.* They are especially distinct on the bark of most birches and cherry trees, and in these finally reach a rather large size. Each lenticel covers the position originally occupied by a stoma in the epidermis of the very young bark. As the stoma grew older its characteristic cells disappeared and were replaced by a spongy mass of thin-walled cells. The lenticels serve for the entrance of gases into the stem and for their passage out of it, and the respiration of the stem is considerably aided by the readiness with which an exchange of gases goes on through these porous spots.

CHAPTER VIII

TIMBER; FORESTRY

100. Wood as a structural material.[1] There are a few disadvantages in the use of wood for many purposes of construction. Wooden fences and buildings are easily destroyed by fire. Wooden posts, bridges, and similar structures, and shingled roofs, are subject to rather rapid decay. Most woods will not stand long-continued friction without wearing out, so that many of the working parts of machines, when made of wood, as they often were by the early settlers in this country, were short-lived.

Some of the advantages of wood for constructive purposes are as follows:

1. Wood is far cheaper than metals; bulk for bulk, it does not, on the average, cost more than one thirtieth as much as iron or steel.

2. Wood is much more easily worked than metals.

3. Weight for weight, some wood is stronger than iron or steel. A bar of hickory will stand a stronger pull lengthwise than one of wrought iron of equal length and weight. A block of the best hickory or long-leaf pine will bear, without crushing, a greater load than a block of wrought iron of the same height and weight.

4. Wood is light and is therefore much more convenient than metals for many purposes of construction, as building vehicles and making packing cases and tool handles.

5. Wood is a poor conductor of heat and on this account is valuable in the construction of houses, railway cars, refrigerators,

[1] See Roth, First Book of Forestry, pp. 232–238. Ginn and Company, Boston.

and other things. Even in buildings or sailing craft composed largely of steel it is therefore found highly desirable to make the floors, decks, and much of the interior construction of wood.

6. Wood is a poor conductor of electricity. This makes it far easier to manage electric wiring in houses or other buildings in which the floor joists and most of the interior finish are of wood than it is in metal structures.

7. When properly finished, wood usually has a highly ornamental surface. This makes it possible to give to the interiors of rooms, railway cars, and street cars a decorative effect which could be obtained with other materials only with much difficulty and expense. It is not easy to imagine how beautiful furniture of moderate price, such as is made from our ornamental woods, could be made from any metal.

101. Wood as fuel. At present coal is the fuel used in most great manufacturing operations, but the world's coal supply is limited and seems likely at no very distant day to become exhausted. The wood supply, with suitable care, can be continually renewed, and wood will probably always remain, as it is now, an important portion of the fuel resources of the world. The fuel value of wood depends somewhat upon its weight per cubic foot, so that such heavy woods as hickory, sugar maple, ash, beech, and most oaks are worth more for heating purposes than such light woods as willow, cottonwood and other poplars, and most pines and other coniferous woods. Charcoal is used a good deal as a smokeless fuel and is the main combustible ingredient in gunpowder.

102. Coniferous woods. Our native woods[1] are best classified into two principal groups — hard woods and soft woods, or coniferous woods.[2] The needle-leaved, or coniferous trees of the country furnish more than three quarters of our timber supply.

[1] "Timber," *Bulletin 10*, Division of Forestry, U.S. Dept. Agr., 1895.

[2] Some of the needle-leaved, or coniferous, trees, such as the larch and the yew, have rather hard wood, and some broad-leaved trees, such as willows, poplars, tulip trees, and buckeyes, have soft wood; but people who deal in timber usually speak of the two general classes as explained above.

The structure of coniferous wood — as seen, for example, on the end of a beam cut off squarely, or on a new lead pencil — is in one respect less complex than that of most hard woods: the wood is chiefly composed of *tracheids* — long, tubular cells with tapering ends — and contains no continuous ducts, though it may contain resin passages. The rings plainly seen on the cross sections of some kinds are due to the difference in diameter between the tracheids formed in early spring and the later ones (fig. 91).

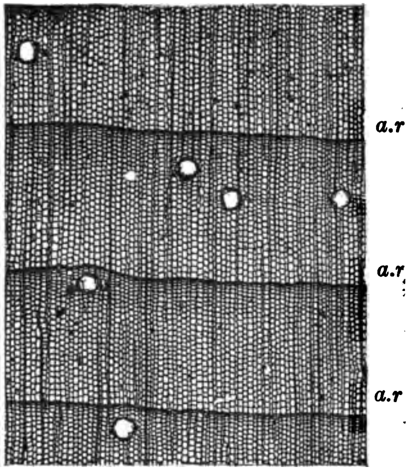


FIG. 91. Cross section of white pine, a typical coniferous wood

a.r, boundaries between one year's growth, or annual ring, and the next. The large, roundish white spots are resin passages that have been cut off. Magnified 15 diameters. Photomicrograph by R. B. Hough[1]

103. Hard woods. Most of the hard wood used for all kinds of construction in this country is furnished by native trees. Of these we have about eighty kinds, the most important ones being the oaks (of about nineteen species). These furnish more than half of our supply of hard-wood timber. Tulipwood, or yellow poplar (*Liriodendron*), is used in great quantities for the interior finish of houses and in the manufacture of woodenware. The wood is soft, free from knots, and furnishes very wide boards. It is not durable when exposed to the weather.

Other important hard woods are ash, beech, birch, chestnut, elm, maple, red gum, and sycamore. Each of these woods has its valuable qualities and its defects, well known to builders

[1] From "Handbook of the Trees of the Northern States and Canada," written and published by Romeyn B. Hough, Lowville, New York.

and other workers in wood. Some woods not among the most important kinds for general purposes are particularly well suited to special uses. Hickory is valuable for ax handles and for wagon and carriage spokes; beech, for shoemakers' lasts, saw handles, and carpenters' planes; black locust and chestnut, for posts and railroad ties, because they decay very slowly even when underground.

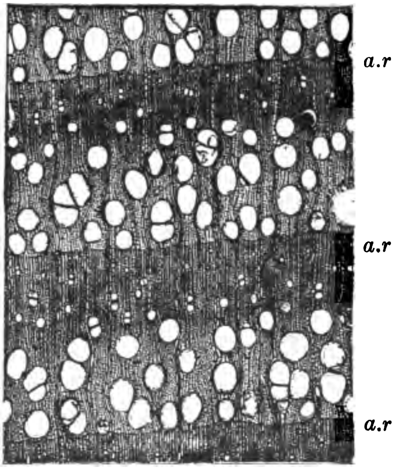


FIG. 92. Cross section of ring-porous wood of sassafras

a.r, boundaries of the annual rings; the wood is ring-porous because the ducts (here shown as oval or roundish spots) are most abundant in the spring wood but almost lacking in autumn wood. Magnified 15 diameters. Photomicrograph by R. B. Hough

Our best native woods for cabinetwork are black walnut, maple, cherry, birch, and some kinds of oak and ash. Red oak is not so strong as white oak, but it has a much coarser grain, so that quartered red oak (cut radially from the log) is among the most ornamental of moderate-priced woods for cabinetmaking and for paneling in the interior finish of houses. Sycamore and sweet gum are also very effective for interior finish, the former being especially important; the supply is very large, and extremely wide boards can be cut from its immense trunks. Large portions of the trunks of old black-walnut trees are often very beautiful in their structure and are extremely valuable, as are also the trunks of bird's-eye maple.

What hard woods used as fuel do you know by sight? What kinds used for construction or other mechanical purposes do you know? What kinds are most readily distinguished from all others? Why?

104. Meaning and importance of forestry. Forestry is the art of forest management. It should be based on the scientific study of woodlands. This study covers all such topics as the distribution of forests over the earth's surface, their dependence on soil and climate, and their own influence upon these. It also discusses their composition as plant communities, their progress from infancy, through youth and maturity, to old age, and their relations to the animal world. The utility

FIG. 93. A prostrate log of sycamore which has lost its bark by decay

Note the extraordinarily twisted grain of the trunk. If this log had been sawed into lumber, it would probably have shown an unusual grain and would have been very valuable for interior finishing

of forests as sources of timber is a most practical forestry topic which stands foremost in the estimation of the public.

Forestry is so extensive a subject that in a portion of a chapter like the present one only a few of its most important sub-divisions can be briefly discussed. Every well-informed person should know, at least in a general way, what forestry is, since the maintenance of some of our best timber lands, and the planting of trees in the prairie and plains region, have become essential to the preservation of the soil and the keeping up of the supply of timber. For about two hundred years one of the chief problems of the pioneer farmer in North America

was to devise ready means of getting rid of the trees which covered the land (fig. 94). A large part of the territory extending east and southeast from the Great Plains region to the Atlantic and the Gulf of Mexico was forest-covered. Now that these immense primeval forests have been destroyed, never to be renewed in their original luxuriance, we are coming to realize that in removing them the early settlers put an end to an almost unlimited source of income, and greatly injured the soil and climate of large areas. Some of the land had to be cleared in order to make tillable fields to grow breadstuffs for the earliest settlers, but it is unfortunate that the clearing process was so well-nigh universal.

FIG. 94. A "deadening"; trees killed by girdling near the base to clear the land for corn

Photograph by United States Forest Service

105. Pure and mixed forests. Some forests are composed almost entirely of a single kind of tree, like the long-leaf pine growth of figure 229. A few of the hard-wood trees, as the birches, oaks, and maples, are not infrequently found growing nearly unmixed with other trees. More frequently, however, two or more kinds of conifers grow intermixed in the same forest, and the hard-wood trees are still more likely to occur with several kinds associated. Thus we find in the same

group oaks, elms, and ashes; in another, oaks and hickories; in another, beeches and maples (fig. 95). Along the fertile river bottoms of the Middle West one may often find a combination of sycamores, oaks, ashes, black walnuts, elms, and hackberries.

106. Tolerant and intolerant trees. A tree which can endure a good deal of shade is said to be *tolerant.* Examples of this are the hemlock and red spruce, among conifers, and the beech and maple, among hard woods. Trees which require much light are said to be *intolerant.* Examples are the white pine and the larch, among conifers, and the oaks, hickories, and chestnuts, among hard woods. As a rule, seedlings require far less light to begin life than is needed to enable the mature tree to reach its maximum size. So it often happens that seedling trees may survive for years on the forest floor, making but little growth until the decay and fall of overshadowing trees, their destruction by wind, or their removal by the lumberman enables the seedling to grow rapidly into a large tree.

FIG. 95. Primeval deciduous mixed forest of maple and beech

The relative tolerance of trees is an important topic in practical forestry, since the succession of forest growths often depends largely upon this factor. White-pine seedlings could not be made to grow under a good stand of pine or hemlock timber, but young hemlocks or red spruces would succeed there. On the other hand, white-pine seedlings can grow in an aspen forest, and white oak and maple seedlings can grow in an oak-maple forest.

107. Problems of forestry. Most of the questions which the practical forester has to consider can be grouped under three heads:

1. How to establish forests on areas naturally treeless or on tracts of perfectly cleared land.

2. How to maintain existing forests for an indefinite period in the most productive condition.

3. How to fell timber and remove it with the least possible damage to the trees that are left standing.

In a book on general elementary botany only a few hints on these most important topics can be given. Every intelligent citizen, however, should at least know that the conservation of our forests is highly essential, and should understand the general bearing which it has on our welfare as a nation.

108. Forest plantations on treeless land. In such treeless regions as the prairies and the Great Plains it is often desirable to establish belts of timber or considerable tracts of woodland. This is done partly for shelter from winds and partly for the timber produced for local uses. The seeds may be planted where the trees are finally to stand, or young seedlings may be procured from a forest nursery. The latter plan is the better, and it is well to have the young seedlings transplanted once or twice before their final planting, to avoid the formation of long roots, the cutting off of which would check the growth of the tree. Both coniferous and dicotyledonous trees are much planted. Some of the most generally available conifers are the white pine, the Scotch pine, the Austrian pine, and several kinds of spruce. Among the desirable dicotyledons are cottonwood (fig. 96), silver (or white) maple, green ash, honey locust, hardy catalpa, red oak, and (in the warmer parts of the country) eucalyptus. In climates such as that of the lowlands of California, *Eucalyptus globulus* is the most rapid growing of hard woods, reaching a diameter of one foot and a height of one hundred twenty-five feet in ten years. To reach this diameter the white oak would require a hundred years.

109. Propagation of trees in woodlands. Many kinds of forest can be so managed that the young trees sown by natural agencies suffice to keep up the stand when the largest trees are felled (fig. 97). The seeds of most conifers are readily carried considerable distances by the wind, and those of many broad-leaved trees, as birches, elms, ashes, maples, and others, are carried in the same way. Squirrels carry many nuts and acorns and often bury them where they can grow. Many birds — for example, the bluejays — carry acorns, and most fruit-eating birds disseminate such seeds as those of the red cedars, wild cherries, hackberry, mulberry, and a few other trees, often carrying them many miles. Tolerant seedlings may establish themselves in the shade of full-grown trees.

FIG. 96. Part of a windbreak of cottonwood, ten years old

Trees planted 5 ft. × 6 ft., thinned to 6 ft. × 10 ft. The trunks will make good lumber, as the lower branches will all be killed by the shade. Photograph by United States Forest Service

The expense of planting seeds or setting out young trees in woodlands is usually so great as to make it unprofitable, since the natural growth will renew itself with a little artificial aid. It is, however, important to clear away undershrubs that are overshadowing desirable seedling trees.

Fig. 97. Young pines starting in partial shade of hard-wood trees
Photograph furnished by Connecticut Agricultural Experiment Station

FIG. 98. Evergreen windbreak of *Eucalyptus* sheltering a California lemon orchard

Photograph by United States Forest Service

Many trees, as oaks, chestnuts, and birches, sprout freely from the stump, and in this way woodlands that have been cut away are renewed much more quickly than they could be by the growth of young trees from the seed. Often it is found

most profitable to allow the sprouts to grow only twenty or thirty years, forming a *coppice woodland*, which is then cut and used for fuel and for making telegraph poles, fence posts, and railroad ties.

110. Tree belts and wood lots as windbreaks. Every one who has observed the conditions in a country partly wooded and partly cleared knows how much less severe is the effect of winter winds in areas protected by neighboring woods. Cattle that are allowed to range out of doors during cold weather always resort to the lee side of wood lots for shelter. Most orchards and many crops, such as winter wheat, are greatly protected from the effects of destructive cold winds in early spring by the presence of trees on the windward side.

Damage from storms which would blow down corn or lodge small grains may be almost entirely prevented by suitably placed tree belts. It has been computed that a single storm in 1862 damaged standing corn in Illinois to such an extent that the loss was almost great enough to have paid for planting four miles of tree belts on every square mile of land affected by the storm.

Hot, drying winds which parch the crops, and those which blow drifts of fine earth or sand from field to field, may be made far less injurious by patches or belts of trees.

For these and other reasons it has been found highly profitable in many of the comparatively treeless states to plant wood lots and belts of trees in such a way as to afford a supply of timber and at the same time protect the cattle and crops of the farm. The kinds of trees planted vary with local conditions. In general, when protection from winter winds is needed, in all the Northern states the belts should consist partly of evergreen conifers.[1]

111. Regulation of the water supply by forests. It is not fully known just how much influence forests exert on the temperature and rainfall of temperate regions. On this account

[1] See Bates, "Windbreaks," *Bulletin 86*, Division of Forestry, U. S. Dept. Agr., 1911.

it has been possible for people interested in lumbering to assert that clearing off the forests may do no harm to the climate of the country. No one should be deceived by such arguments, since it is a well-ascertained fact that *the water supply of any region is made far more irregular by the removal of its forests.* The annual rainfall may not be greatly changed, but the rivers of a deforested country are likely to overflow their banks after all heavy rains, and then almost disappear during the driest part of the summer. A notable example of this summer shrinkage in rivers is that of the Susquehanna; in 1816 it was estimated that this river delivered five hundred million gallons per day at its season of minimum flow; in 1874 this had shrunk to less than half the amount, although the annual rainfall remained about the same.[1] Every one who has lived in a prairie country knows that the run-off from grasslands is so rapid that ereeks which, during a dry time, consist merely of a series of pools may be running bank-full after an hour or two of heavy rain. From plowed land the run-off is even more rapid than from grass-covered land. It is difficult to ascertain just what proportion of the total rainfall is temporarily held by the forest floor. On careful observation of a wooded basin in the Cévennes Mountains in southern France, in which somewhat more than 50 per cent was forest, it was found that after two days of heavy rain more than eight ninths of the total rainfall was held by the soil; water so held may then run away gradually.[2]

The action of forests in retaining water and slowly distributing it is largely due to the following causes:

1. Snow melts gradually in the shade of forests, and so the water derived from its thawing is given off little by little.
2. Evaporation goes on slowly in the shade.
3. The forest floor is often covered to a considerable depth with a layer of highly absorbent material, such as decaying

[1] See Fernow, "Forest Influences," *Bulletin 7*, Division of Forestry, U. S. Dept. Agr., 1893.

[2] Ibid.

leaves and branches. Not infrequently it is covered with moss. The soil of the forest, abounding in humus, retains water much longer than average soil in open fields. All of these factors coöperate to hold back the run-off from wooded areas. It is therefore of the highest importance that such regions as the White Mountains,[1] the Adirondacks, the central and southern Appalachians, and western mountain ranges which are used as sources of water for irrigation should be forested.

112. Forest growth prevents erosion. Along with the value of the forest in regulating the flow of streams, account must be taken of its importance in preventing the washing away, or *erosion*, of the earth's surface. Not only mountains and hillsides but cultivated slopes everywhere are subject to great losses by washing during thaws after snows and during rainstorms. How much earth is thus annually carried to the Gulf by the Mississippi alone has already been stated (sect. 24). Figure 239 represents an early stage in the formation of gullies on a steep slope after clearing. The land is already past the stage in which it can be cultivated in the ordinary way. Left to itself the tendency is for the washing to continue until the hillside becomes a series of miniature ravines, strewn with bowlders and separated by bare ridges. Thousands of acres in the southern United States and hundreds of thousands in some of what were once the most fertile parts of southern Europe have been ruined in this way. Such destruction may be prevented by retaining hillsides in a wooded condition, or at least by leaving belts of trees at intervals, running at right angles to the lines of slope. The early stages of erosion may be checked by damming the principal gullies with logs, stones, and brushwood, and then replanting with suitable

[1] Recent investigations in the White Mountain region by the United States Geological Survey show that the run-off on two drainage basins, each of about five square miles, on the Pemigewasset River, was very unequal. One basin was covered with virgin forest; the other had been deforested and burned. The run-off from the latter basin during seventeen days in April (including three extensive storms) was about double that from the forest-covered basin.

trees and bushes. Contour plowing (that is, plowing around the hill instead of up and down it), terracing, ditching at right angles to the lines of slope, and underdraining, all help to prevent erosion.

113. Rules for forest management. For a detailed account of the mode of keeping up the productiveness of woodlands and of handling timber one must go to special treatises on forestry.[1] In this place there is room to name only a very few of the things to which the forester, or manager of timber-lands, must attend.

1. A *timber forest*, or woodland, consisting in considerable part of full-grown trees, should be cut over on a selective plan; that is to say, only those trees should be felled which are nearly or quite full-grown, or which are too much crowded or in some way imperfect or diseased. This kind of selection may not be possible in case the location of the forest is rather inaccessible, and therefore large gangs of men must be taken into the woods and the cutting all done within a limited season. As far as possible the felling must be so managed that promising young trees are not barked or otherwise injured by the falling trunks of the trees which are cut.

2. In managing coppice woods the trees must be cut as soon as they reach a merchantable size — usually in from twenty to forty years.

3. During the period of most active growth all woodlands should be kept covered with a reasonably close stand, so as to secure self-pruning and to discourage the growth of much-branched trees, like those shown in figures 99 and 219, which, when cut into lumber, will be very full of knots.

4. Forest fires must be prevented, especially in woods of coniferous trees. No fires for any purpose should ever be kindled during dry weather in the heart of such woodlands, except in moderately large clearings that are free from brush. Cutting up large tracts of forest into smaller portions by

[1] For elementary principles, see Roth, First Book of Forestry. Ginn and Company, Boston.

means of roads helps to keep small fires from spreading, but in warm dry weather a coniferous-forest fire under full headway makes such leaps that it is seldom stopped until it reaches extensive clearings or rivers or other large bodies of water.

FIG. 99. Oak trees growing in the open
White oak at the left and red oak at the right

5. Parasitic fungi and the saprophytic kinds which cause the decay of fallen trunks and branches or felled trees (figs. 182 and 199) should be burned, when this is not too expensive and when it can be managed without danger of starting forest fires.

6. Wood-boring and leaf-eating insects should be killed, if the expense of the process is not too great. It is suggested, for example, that the great damage caused by the spruce-destroying beetle, which kills mature trees by mining the bark of the trunk, may be much lessened. This can be accomplished by cutting and removing most of the infested trees or by girdling trees early in June, to expose them to the attacks of the beetles, then felling and either peeling them or immersing them in water, to destroy the insects before the new crop of beetles emerges from the under the bark the following June.[1]

FIG. 100. A carnivorous beetle (*Calosoma sycophanta*) which destroys the caterpillars of the gypsy moth

These beetles have been imported from Europe, and successful colonies of them established in New England. After United States Department of Agriculture

One of the most effectual means of destroying some injurious insects consists in introducing into the region where they abound parasitic or other insects which will kill great numbers of the objectionable species. Plant lice, for instance, are thus killed by ladybugs. Vigorous attempts are now being made to exterminate the gypsy moth in New England by means of parasites and by carnivorous insects (fig. 100) which attack and kill the moth at some stage of its existence. The caterpillars of this moth are extremely destructive to many kinds of trees, which they strip of their leaves in a short time. More than a million dollars has probably been expended in Massachusetts alone in trying to get rid of this pest. The moth was introduced into America in 1869, by a scientist who lived at Medford, near Boston, in the course of some most unfortunate experiments on silk-producing insects.[2]

[1] See "Insect Enemies of the Spruce in the Northeast," *Bulletin 28*, New Series, Division of Entomology, U.S. Dept. Agr., 1901.

[2] "The Gypsy Moth in America," *Bulletin 11*, New Series, Division of Entomology, U.S. Dept. Agr., 1897.

7. Cattle should not be pastured in woods in which it is important to protect the growth of young seedling dicotyledonous trees, but they do not greatly injure mature trees. Sheep pasturing and forestry cannot thrive together, since by browsing the sheep destroy many young seedling trees. On grassy hillsides and mountain sides sheep, by close grazing and by cutting the turf to pieces with their sharp hoofs, soon kill the grassy cover and pave the way for extensive erosion. Great damage has been done in this way in the Rocky Mountain and Pacific Slope regions of our own country. In southern Europe the pasturing of sheep and goats has led to the conversion of great areas of comparatively fertile mountain sides into bare ridges and bowlder-lined torrent beds.

PROBLEMS

1. Irrespective of the hardness, what means are there of distinguishing between coniferous woods and nonconiferous woods?

2. Explain how you can recognize red cedar, cypress, white pine, oak, sycamore, hickory, and black-walnut wood. List the kinds of wood that you know well.

3. What kind of wood is commonly used in your region for the frames of houses? for shingles? for packing cases? for barrels? for fence posts? for railroad ties? for fuel? Explain why each is chosen. What is the most extensive wood-using industry of your locality?

4. What kind of wood is used for lead pencils? for matches? for toothpicks? for rulers? for shoe pegs? Why?

5. Have you become acquainted with any well-grown tracts of self-sown forest? Of what kinds of trees do they mainly consist? How much does the nature of the soil have to do with the constitution of forests that you have seen? Does cultivation affect forest trees?

6. Are coppice woodlands composed of conifers or of hard woods? Why?

7. What rules of forest management are most frequently violated in timber lands that you have seen? Why?

8. What trees are most frequently planted for shade in your vicinity? Give the good and the bad points of each.

9. Get copies of your state forest laws; study and report on them.

CHAPTER IX

FLOWERS

114. The organs of the flower. Although a brief discussion of the parts of the flower was presented in Chapter II, it will be necessary here to consider them more carefully. Many of the most highly organized flowering plants have flowers with four sets of organs, as shown in figure 101. The outer set (the *calyx*) consists of parts called *sepals*, which are usually green and rather leaf-like. Just within or above the calyx comes the *corolla*, which consists of leaf-like parts (*petals*) usually of some other color than green. Next comes a set of *stamens*, which very commonly appear as stalked organs, each with an enlarged, knob-like tip. Finally, the innermost, or uppermost, set of organs consists of *carpels*, which, if united, constitute the compound *pistil*, or, if separate from one another, constitute the simple pistils.

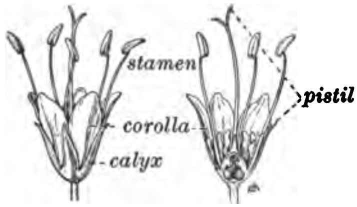


Fig. 101. Flower of *Hydrophyllum*, side view and lengthwise section

A good example of a flower in which the parts of each set except the stamens appear to be more or less joined together. Modified after Decaisne

Not many flowers have organs as distinct — that is, as wholly separate from each other — as they are in the live-forever (fig. 102). In the *Hydrophyllum* (fig. 101) the organs of each set, except the stamens, appear to be more or less united. The pistil seems to be all of one piece, except that it is two-forked at the tip. Hardly any two kinds of flowers have exactly the same forms and arrangements of the floral organs. A few of the forms are figured in Chapter X.

115. What is a flower? A hasty examination of an ordinary flower does not give much evidence as to the relation which its organs bear to the parts of the plant already studied; that is, to the root, the stem, and the leaf. There is, however, plenty of evidence to show that *the flower is a much-shortened and otherwise modified branch, specialized for the production of seed.* The floral organs therefore correspond to leaves. One of the most easily understood evidences of the branch-like character of the flower is the fact that the positions of the flower buds on the branch are similar to those of leaf buds; that is, they are usually either axillary or terminal. Moreover, in its earliest stages a flower bud is developed much as a leaf bud is.

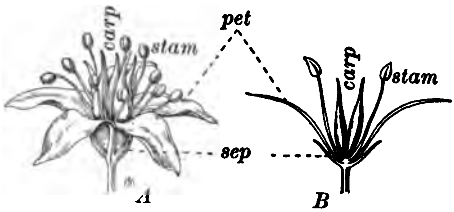


FIG. 102. Flower of live-forever (*Sedum*)

A, entire flower, *B*, lengthwise section; *carp*, carpels; *stam*, stamens; *pet*, petals; *sep*, sepals. An excellent example of a flower in which the parts of each circle are of the same number and all separate. Somewhat enlarged. After Schimper

116. The arrangement of the organs of the flower. The floral organs spring from the *receptacle*, an expanded portion of the flower stalk. Sometimes, as in figure 102, the receptacle is but little enlarged; sometimes, as in figure 103, it is much enlarged; often it is convex or concave. Usually in dicotyledons the floral organs are arranged in *whorls*, or *cycles* (that is, in circular fashion), on the receptacle, but sometimes part or all of them are in spirals. In case there is the same number of parts in each cycle, each part commonly stands opposite a space between two members of the

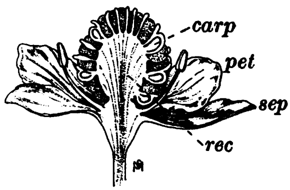


FIG. 103. Lengthwise section of flower of a buttercup

carp, carpels; *pet*, petal; *sep*, sepal; *rec*, large convex receptacle on which the numerous carpels are borne. Somewhat enlarged. After Baillon

adjacent cycles; that is, each petal opposite a space between two sepals, each stamen opposite a space between two petals, and so on. Very often this alternate arrangement of the members of successive whorls is less evident because one or more whorls have more numerous or fewer parts than the others, as in the case of the buttercups and crowfoots (fig. 103), roses, and many other familiar flowers. In many cases, as in the knotgrass (fig. 125), only one set of floral leaves occurs. Such flowers are said to lack petals and are known as *apetalous*. Some flowers, as those of the lizard's-tail (fig. 104) and the willow (fig. 105), are wholly destitute of calyx and corolla.

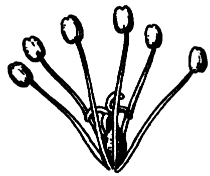


FIG. 104. Flower of lizard's-tail, with no calyx or corolla

After Engler

117. Staminate flowers and pistillate flowers. Such flowers as are shown in figures 101–104, containing both stamens and pistils, are said to be *bisexual*.[1] Those which contain stamens but not pistils or pistils but not stamens, like those of the willow (fig. 105), are said to be *unisexual*. Many families of dicotyledonous trees and shrubs, such as the Willow family, the Oak family, and others, have unisexual

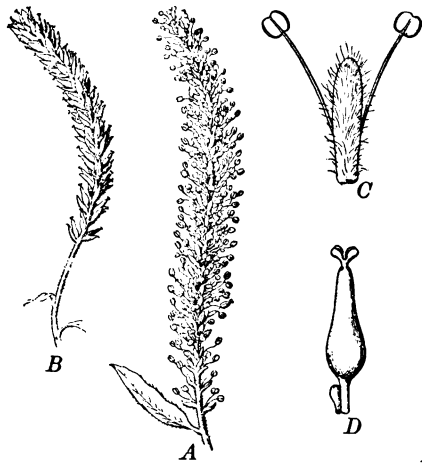


FIG. 105. Diœcious flowers of white willow (*Salix alba*)

A, staminate catkin, natural size; *B*, pistillate catkin, natural size; *C*, staminate flower, magnified; *D*, pistillate flower, magnified. After Cosson and De Saint-Pierre

[1] The flower itself is not sexual at all, as will appear later, but these terms have come into general use, and their application to the two kinds of flower seems likely to continue.

flowers. A flower which has stamens only is said to be *staminate*, and one which has pistils only is said to be *pistillate*.

118. The perianth. In most flowers of dicotyledons the calyx and the corolla are quite unlike in color and texture, as they are, for instance, in roses and pinks. But in many other cases, as in the (monocotyledonous) lilies, there is no sharp distinction in appearance between sepals and petals. This fact makes it convenient to have a single name for calyx and corolla taken together, and the word *perianth* is used to include both sets of organs.

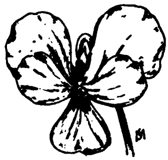


FIG. 106. Bilaterally symmetrical flower of a violet

After H. Müller

When the calyx is composed of separate sepals, and the corolla of separate petals, these parts are said to be *distinct*, and the flower is *chorisepalous* or *choripetalous* (figs. 102 and 103). In the most specialized flowers, both of monocotyledons and of dicotyledons, the calyx, the corolla, or both, appear as if grown together into a cup or tube (figs. 101 and 123). This condition arises from the fact that the floral envelopes did not originate in the form of separate sepals or petals on the surface of the receptacle, but as zones of tissue which developed into a tubular or cup-shaped perianth. In this case the flower is said to be *synsepalous* or *sympetalous*. Sometimes the receptacle itself may be tubular or basin-shaped and bear the perianth on its rim. Generally teeth or lobes of the calyx or corolla show of how many parts it is composed.

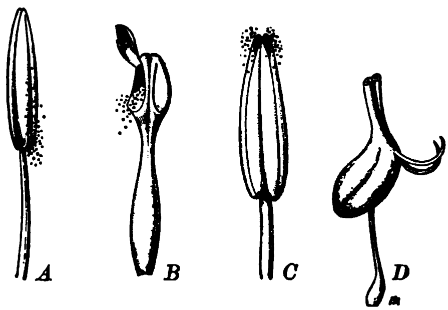


FIG. 107. Various types of anther

A, iris, discharging pollen by a longitudinal slit; *B*, barberry, discharging pollen by uplifted valves; *C*, nightshade, *D*, bilberry, both discharging pollen through holes or pores at the top of the anther. *A*, *B*, *C*, after Baillon; *D*, after Kerner

119. Symmetry of the flower. Except in a comparatively small number of cases (of which the familiar canna, or Indian shot, is a good example) the perianth usually shows some kind of symmetry. Either (as in fig. 102) the parts are arranged in a radial fashion, like the points of a star, or else they have corresponding halves in one plane to the right and left of an axial line, as in pansies and violets (fig. 106), in the most familiar flowers of the Pea family, and in those of the Mint family. Flowers with radial symmetry are said to be *actinomorphic*, and those with corresponding halves are said to have bilateral symmetry, or to be *zygomorphic*.

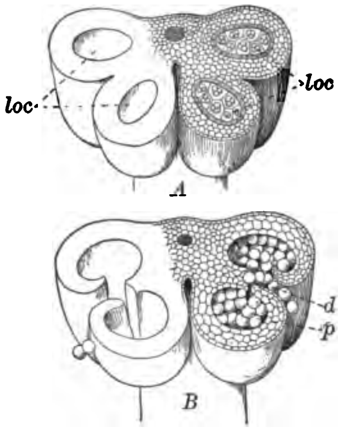


FIG. 108. Diagrams to show structure of an anther

A, younger stage, with four chambers, or *locules* (*loc*), containing pollen mother cells dividing to form pollen grains; *B*, an older stage, in which the pollen grains (*p*) are fully formed and each pair of locules is uniting to form a pollen sac, which will split open and discharge along the line of dehiscence (*d*). After Baillon and Luerssen

Sometimes, as in the Milkweed family, the corolla has extraordinary forms which facilitate seed production by the aid of insect visitors (fig. 134).

120. Parts of the stamen; union of stamens. Many stamens have a form similar to that shown in figure 107, *A*, consisting of a rather slender stalk (the *filament*) which bears a stouter structure, the *anther*. Anthers which have no filaments are said to be *sessile*. Within the anther the stamen produces a powdery or pasty substance known as *pollen*, which, when magnified, is seen to consist of minute grains (fig. 117). These differ greatly in form and markings in different families of plants. The mode of origin of the *pollen sacs* in which pollen is produced is partially shown in figure 108. When the sacs are fully mature, they open and allow their contents to escape.

Stamens are often joined by their filaments so as to form one, two, three (fig. 109), or several groups. In other cases they are joined by their anthers into a single group which surrounds the pistil (fig. 110). In the latter case the pollen is often at length forced out of the anther tube in a single mass by the lengthening pistil (fig. 111).

FIG. 109. Flower of St.-John's-wort, with the numerous stamens in three groups

The sepals and petals have been removed. After Warming

121. Carpel and pistil. Although the entire flower is more or less engaged in the work of seed production, it is the *carpel* (from a Greek word meaning "fruit") in which the rudimentary seeds, or *ovules*, originate. In its simplest form, as in the pines and related trees, the carpel consists of a scale of the seed-bearing cone (fig. 224). Each young scale bears at its base an ovule, or rudimentary seed. Among the higher flowering plants the carpel produces the ovules inside a cavity known as the *ovary* (fig. 112).

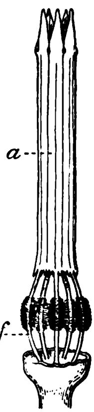


FIG. 110. Stamens of a thistle, with anthers united into a ring

a, united anthers; *f*, filaments, bearded on the sides. After Baillon

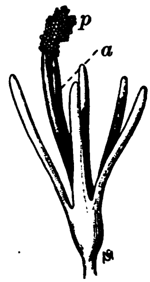


FIG. 111. A single flower of the hundred or more which compose the head of flowers of the Canada thistle

a, the anthers united to form a tube; *p*, the clump of pollen grains forced out from the anther tube by the lengthening of the pistil within the tube. After H. Müller

The carpellary portion of the flower of the higher seed plants (whether it consists of one or more carpels) is known as the *pistil*. Evidently, if the flower has but one carpel (fig. 105), the words *carpel* and *pistil* as applied to such a flower mean the same thing. If there are several carpels, each is one of the units of which the entire pistil is built (fig. 102). A pistil

consisting of a single carpel is said to be *simple*, and one of several carpels, *compound*. The fact that a pistil consisting of several joined carpels is really compound is generally evident from the presence of several chambers, or *locules*, in the ovary (fig. 113, *A*), from the occurrence of several ovule-bearing areas (fig. 113, *B*), or from the forked divisions of the upper part of the pistil (fig. 112). Besides the ovary a pistil often has a stalk known as the *style*, and (in all but the lowest

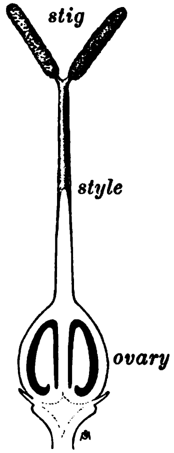


FIG. 112. A pistil with the ovary cut through lengthwise

stig, the stigma

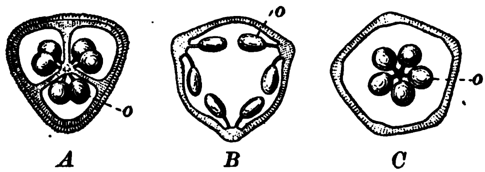


FIG. 113. Three modes of bearing ovules

A, ovary three-loculed, with the ovules, *o*, borne on the axis (*central placenta*) formed by the united partitions; *B*, ovary one-loculed, ovules, *o*, borne on the ovary wall along three *placentas*; *C*, ovary one-loculed, ovules, *o*, borne on a *free central placenta*. After Behrens

seed plants) there is a pollen-receiving portion called the *stigma*. The relation of these parts is easily understood from an inspection of figure 112. Often (fig. 114, *B*) the style is lacking and the stigmas are found on the summit or on the side of the ovary. In this case the stigmas are said to be *sessile*.

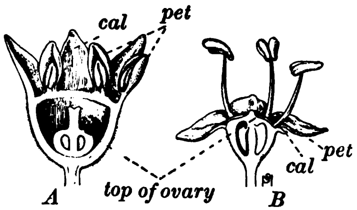


FIG. 114. *A*, perigynous flower of buckthorn; *B*, epigynous flower of English ivy — both lengthwise sections

cal, calyx: *pet*, petals. Note the curious hood-like petals of the buckthorn, each inclosing an anther. *A*, after Berg and Schmidt; *B*, after Wossidlo

122. Relation of the ovary to surrounding organs. In the simplest type of flower having all four kinds of floral organs (fig. 102) the receptacle bears the ovary or ovaries at or near

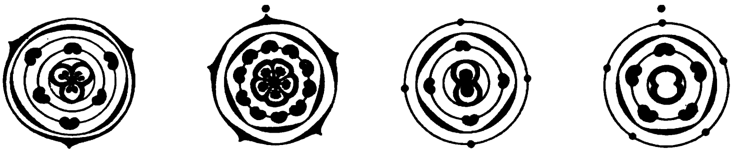
its apex. The other organs are borne in successive cycles farther and farther away from the tip of the receptacle. But in many of the most highly specialized kinds of flowers the receptacle, as previously stated, bears a sort of tubular or cup-like extension, on the rim of which the petals and the stamens are so borne as to surround the ovary (fig. 114, *A*); or the extension of the receptacle may rise to the top of the ovary, so that the petals (if present) and the stamens appear to grow out of its top surface (fig. 114, *B*). When the ovary stands wholly above the surrounding floral whorls, it is said to be ***superior***, or the flower is ***hypogynous*** (meaning "under the ovary"). When the ovary is encircled by the other floral whorls, it is said to be ***half-inferior***, or the flower is ***perigynous*** ("around the ovary"). When the petals and stamens appear to spring from the top of the ovary, it is said to be ***inferior***, or the flower is ***epigynous*** ("upon the ovary"), as in the evening primrose, (fig. 115).[1]

FIG. 115. Flower cluster of evening primrose

123. Floral diagrams. Lengthwise sections of the flower may be represented by simple diagrams like that of figure 102, *B*. These are convenient to show the relation of the other whorls to the pistil. Cross sections like those of figure 116 show the

[1] The suffix *gynous* refers to the ovary only by a fanciful figure of speech.

relative positions of the members of the different whorls. Such sections do not usually show just what would appear on the cut surface made by slicing the flower across at right angles



A *B* *C* *D*

Fig. 116. Floral diagrams

A, Lily family; *B*, Heath family; *C*, Madder family; *D*, Composite family. The dot above the diagram indicates the position of the stem or axis which bears the flowers. The sepals are distinguished from the petals by being represented with midribs. In *B* the alternate stamens are printed lighter, since some flowers of this family have five and some ten stamens. After Sachs

to its axis; they rather give the section that would be obtained by raising or lowering the successive whorls until all stood on the same level, and then making a section. It is usual to distinguish sepals from petals by representing the former with a midrib, and to represent the section as passing through the anthers and ovaries of the stamens and pistils, respectively.

CHAPTER X

POLLINATION AND FERTILIZATION

124. Pollination. In the great majority of flowering plants seed production depends indirectly upon pollen. Of course the pollen grain, in order to act, must be transferred from the anther, where it was formed, to the pistil, in which are the ovules to be affected. This transference of pollen is called *pollination.*

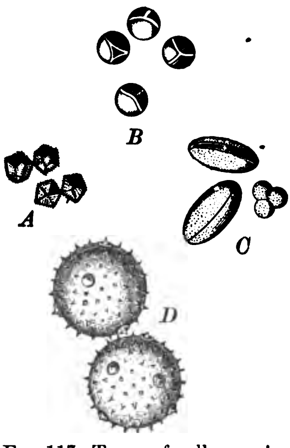


FIG. 117. Types of pollen grains

A, dandelion; *B*, hemp; *C*, gentian; *D*, squash. All greatly magnified. After Kerner

In the higher seed plants the pollen is received on the surface of the stigma, which is usually rough, moist, and sticky, and therefore readily retains the grains which reach its surface. The details of the pollinating process differ so much in different kinds of flowers that even a mere statement of the various types requires considerable space. The significance of pollination will appear more clearly if we first give a very brief account of the results of pollination, and then consider a few of the modes of transference of pollen.

125. Pollen grains; formation of pollen tubes. The form of pollen grain for any given kind of flower, as a lily, a hollyhock, or a cucumber blossom, is quite constant, but those of different kinds are so often unlike that the whole number of forms observed is very great. Usually the grains are separate, like those shown in figure 117, but in many kinds they are united by

extremely slender, sticky threads. The mature grain contains two nuclei, a *generative nucleus* and a *tube nucleus*. Contact of the pollen grain with the moist stigmatic surface brings about osmosis, which results in distention of the pollen grain. At some point the outer coat becomes ruptured and the inner thin coat protrudes through the opening and is the beginning of the *pollen tube*. Then a portion of the contents of the grain passes out into the pollen tube, which is developed from the thin inner coat of the pollen grain (fig. 118, *A*). The pollen tube contains a tube nucleus (*t*) near its tip and a generative cell (*g*) somewhere farther back. At length the generative cell divides into two *male nuclei*, these develop into *male cells* (fig. 118, *B*), and the tube nucleus sooner or later disappears.

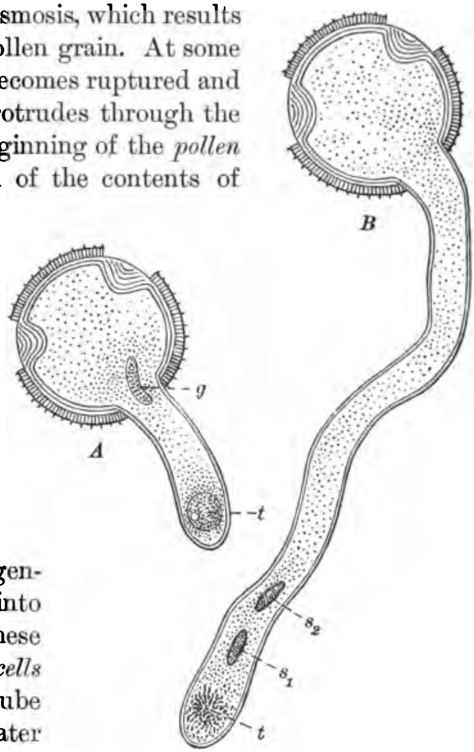


FIG. 118. Germination of the pollen grain of a dicotyledon

A, an early stage in the germination; *B*, later stage, with the tube rather fully developed; *g*, generative cell; *t*, tube nucleus; s_1, s_2, male cells formed from the generative cell. It is apparent that when the growth of the tube is far advanced, the tube nucleus (*t*) almost disappears. Much magnified. After Bonnier and Sablon

126. Course of the pollen tube. The pollen tube readily makes its way between the exterior cells of the stigma and passes onward to the ovary. Sometimes it traverses a tubular passage and sometimes it penetrates the tissues, aided by the corroding action of ferments which it secretes. It is

supposed that the pollen tube is nourished by the cells that are broken down in the path of the tube. The time required for the pollen tube to reach the ovule varies in different plants, ranging from a few hours to more than a year. Usually the tube finds its way into the ovule through a minute opening known as the *micropyle* (fig. 119, *m*), but in some plants it grows directly through the substance of the ovule.

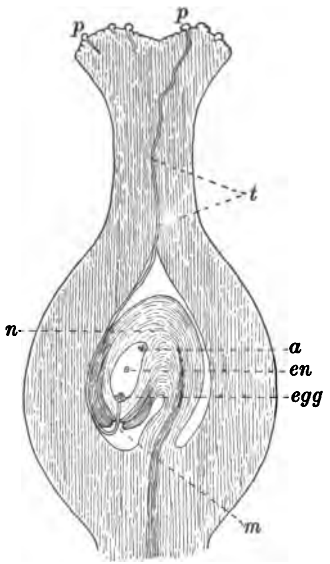


FIG. 119. Diagram to illustrate course of the pollen tube during fertilization

p, pollen grains; *t*, pollen tube; *n*, *nucellus*, or body of the ovule; *a*, *antipodal cells* of embryo sac; *en*, endosperm nucleus of embryo sac; *egg*, the egg apparatus, consisting of the egg cell and two coöperating cells; *m*, the *micropyle*, or small opening, through which, in most ordinary flowering plants, the pollen tube makes its way to the egg at the tip of the embryo sac

127. Fertilization. On entering the ovule, one of the male cells unites with the *egg nucleus* of the embryo sac, which is within the ovule, and the other male cell in some cases, or perhaps usually, unites with the central nucleus of the embryo sac to form the *endosperm nucleus* (fig. 119, *en*). The nature and function of the latter union are not as yet perfectly understood. The fusion of egg nucleus and male cell is, however, a very common and most important phenomenon, occurring in many of the simpler plants as well as in the higher ones. In general it may be said that *fertilization consists in the union of the nucleus of a male cell with the nucleus of an egg cell.* Other illustrations of this will be given in Chapters XV–XVIII. After fertilization the egg rapidly grows into the embryo of a new plant. The ovule also grows

and, together with the embryo, they constitute the seed. Under favorable circumstances the seed may germinate and the embryo grow into an adult plant. One pollen grain may suffice to fertilize an ovule, but the result is more certain if there are several germinating pollen grains for each ovule, though but one male cell unites with one egg.

128. Pollination an ecological subject. Before considering the ecology of flowers it is necessary to explain what is meant by *plant ecology.* It is impossible to study plants in any all-round fashion without paying a good deal of attention to the way in which they are influenced by their surroundings. Any change in the temperature, light, water supply, or supply of raw materials for food-making is sure to affect the plant in some way. Hillside, plain, swamp, lake, or sea — each has its own *flora*, or set of plant inhabitants, which can thrive under the conditions found in their growing place. Plants are also greatly affected by the favorable or unfavorable influences exerted on them by their animal and plant neighbors. *The whole subject of the relation of plants to the environment in which they live is known as plant ecology.* In earlier chapters much has been stated, and still more suggested, that concerns this side of botany, but the subject was not treated in detail, because it is one of the most difficult departments of botanical science and its study is as yet only fairly begun. In this chapter most that is to be said of the processes of pollination should be classed as pertaining to the ecology of flowers.

129. Relation of types of floral structure to pollination. Probably most students of plants, from the earliest times, were somewhat puzzled over the great variety in form, coloration, odor, and other characteristics shown by flowers, but until about a hundred and fifty years ago no botanist seems even to have reasoned about the facts that some flowers are over a yard in diameter, while others are almost microscopic; that some spread the perianth widely and others are narrowly tubular or urn-shaped; that some are sweet-scented, others carrion-scented, and others odorless; that some have extremely

light, dust-like pollen, while others have pollen which coheres in sticky masses — and so on, with a multitude of other differences. These singular facts were first explained in part by two eighteenth-century German botanists, Kölreuter and Sprengel, working independently of each other. Little was afterwards done to clear up the subject until Charles Darwin and a host of other investigators, beginning soon after the middle of the nineteenth century, worked out the details of the methods of pollination.[1]

As a result of these studies it may be said that *flowers owe most of their structural and other characteristics to the fact that these things have enabled them to secure the needed pollination.*

130. Classification according to means of pollination. It is impossible in any brief way to give much of an account of the groups into which flowers are divided with reference to their means of securing pollination. Before outlining these groups it is necessary to define the word *nectar*. This name is given to the sweet liquid found in many flowers — for example, columbine, honeysuckle, and red clover. The nectar is secreted by special organs known as *nectar glands* (figs. 120 and 129) and is often stored at the base of the corolla, sometimes in little pouches, as in the columbines and the honeysuckles.

FIG. 120. Flower of grape, with nectar glands (n) at the base of the ovary

Some of the most important groups of flowers, classified according to their qualifications for securing pollination, are the following:

1. Flowers mostly with inconspicuous perianth, and usually without nectar, destitute of odor, generally with moist or sticky pollen, with knob-like or club-shaped stigmas.

2. Flowers with inconspicuous perianth, destitute of odor, without nectar, with dust-like pollen, with feathery stigmas (fig. 121).

[1] See Knuth-Davis, Handbook of Flower Pollination, Vol. I. Clarendon Press, Oxford.

3. Flowers with conspicuous perianth, often with odor, often with nectar, usually with moist or sticky pollen, with knob-like or club-shaped stigmas.

A good example of 1 is the flower of the peppergrass (*Lepidium*); of 2, the flowers of the grasses; of 3, the showy garden flowers, such as lilies, pinks, and roses.

131. Modes of pollen-carrying. Each of the three groups just described corresponds to a different mode of transference of pollen from anther to stigma.

The flowers of 1 either themselves carry pollen from the stamens to the stigma *of the same flower* (for example, by the curving inward of the stamens as the flower matures) or have it carried from stamens to pistil within the flower by insects which visit the flower, usually in search of pollen. Such flowers are said to be *self-pollinated.*

In the flowers of 2 the pollen is carried, preferably from a flower on one plant to a flower on another plant, by aid of the wind or, in the case of a few aquatic plants, by water. Such flowers are said to be *wind-pollinated* or *water-pollinated.*

FIG. 121. Pistil of timothy, with feathery stigmas

sti, stigmas. Magnified about 20 times

In the flowers of 3 the pollen is carried, preferably from a flower on one plant to a flower on another plant, usually by insects that visit the flowers in order to secure food.[1] Such flowers are said to be *insect-pollinated.*

132. Self-pollination and cross-pollination. There is a very great physiological difference between self-pollination (1) and cross-pollination (2 and 3). In self-pollination the male cell and the egg nucleus with which it unites originate in the same flower; in cross-pollination they originate in different flowers, preferably from flowers borne on different plants.

[1] Sometimes the pollen is carried by birds, bats, snails, or other animals.

In many kinds of plants self-pollination is entirely effective. In others it produces seed which is good but not so abundant or so sure to grow into vigorous plants as that which is due to cross-pollination. In still other plants cross-pollination is absolutely essential to the production of seeds that will grow at all.

FIG. 122. Stamens and pistils of round-leaved mallow

The flower has been open for a considerable time, and the stigmas have curved so as to touch the anthers and in this way absolutely to insure self-pollination. After H. Müller

To the fact that self-pollination is in many cases not wholly satisfactory, but better than none at all, is probably due the existence of many flowers like the common dooryard mallow, or "cheeses," which has moderately showy petals and is often cross-pollinated by insects, but can also pollinate itself by the contact of the curving stigmas with the stamens (fig. 122). Such flowers are sometimes able to secure insect pollination, but in default of this they do produce a crop of seeds as a result of their self-pollination.

133. When self-pollination is advantageous; *cleistogamous* flowers. Some flowers are usually self-pollinated except when cross-pollinated by accident or human agency. Wheat is a notable instance of the kind, and apparently self-pollination can go on in this grain for a long period without injury to the fertility or the robustness of the offspring.[1] Experiments in raising selected varieties of tobacco seem to show that in this plant

FIG. 123. Facilities for insect-pollination or self-pollination in flowers of the matrimony vine (*Lycium*)

In the flower at the left (earlier stage) the anthers are spread apart and are likely to come in contact with insect visitors; in the flower at the right (later stage) the anthers close together over the stigma, insuring self-pollination. After Knuth

[1] See "Wheat: Varieties, Breeding, Cultivation," *Bulletin 62*, Univ. of Minn. Agr. Exp. Sta., 1899.

self-fertilization, for several generations at any rate, produces better results than cross-fertilization.[1]

Whenever cross-pollination by the wind or by the agency of animals is impossible, it is evident that self-pollination would be advantageous, since it is infinitely better than no pollination at all. Many highly successful weeds owe their predominance partly to the fact that they produce good seed after self-pollination.

FIG. 124. A violet with cleistogamous flowers as seen in late July or early August, after the conspicuous flowers have disappeared

cl, cleistogamous flowers; *caps*, capsules produced by earlier flowers of the same sort

Since cross-fertilization at intervals appears to be sufficient to keep up the strength and fertility of many kinds of plants, there might be some advantage in uniting the certainty which characterizes self-pollination with the renewal of strength which comes from cross-pollination. Violets and many other less familiar plants unite the two methods by producing ordinary showy flowers and also inconspicuous closed, or *cleistogamous*, flowers. In violets the latter are borne on flower stalks close to the ground (fig. 124) and usually, before maturing, become partially buried in the earth. Pollination occurs within the closed flower, the pollen tubes developing within the anthers and making their way to the stigma. The cleistogamous flowers produce many more seeds than the showy ones, but the latter insure at least occasional cross-pollination since they are freely visited by bees and other flying insects.

[1] See "Tobacco Breeding," *Bulletin 96*, Bureau of Plant Industry, U.S. Dept. Agr., 1907.

It is worth while to mention the fact that the characters of the cleistogamous flowers of some violets are so sharply defined that they are of much use in enabling the botanist to distinguish one species from another.

134. Variety of means for pollination. The details of the process by which some kinds of pollination are secured are most complicated. It has taken the studies of many botanists, based often on thousands of observations and carried through a lifetime, to work out our present fairly exact knowledge of most of the methods. Beginners in botany, in a school course, can hardly do more than follow in a very few instances some of the steps of the original investigators of the pollination of flowers. Merely reading about the processes is not enough; the flowers must be watched out of doors, and then their structures carefully examined in the laboratory.

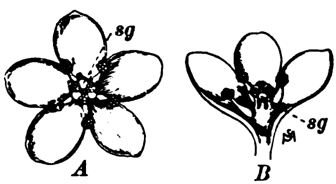


FIG. 125. Self-pollinated flowers of knotgrass (*Polygonum aviculare*)

A, top view; *B*, lengthwise section. Five stamens bend outward and the other three bend inward until their anthers overhang the stigmas *sg*, thus making self-pollination extremely easy. Magnified about 6 diameters. After H. Müller

In the present chapter only about ten floral types will be briefly discussed, out of nearly thirty under which flowers have been classed with reference to their form and mode of securing pollination.[1]

135. Knotgrass[2]; self-pollination. The common dooryard weed known as knotgrass, knotweed, or doorweed is one of the best examples of a plant with flowers suited only for self-pollination. The flowers (fig. 125) are very small (often not as large as the head of a pin), greenish, and borne singly in the axils of the leaves. They are destitute of nectar and without odor, so they do not attract insects. There are usually eight stamens, five outer and three inner ones; these latter, on

[1] See Knuth-Davis, Handbook of Flower Pollination, Vol. I. Clarendon Press, Oxford.

[2] *Polygonum aviculare.*

maturing, close over the stigmas and insure self-pollination. The fact that seeds are abundantly produced shows that the pollination is effective.

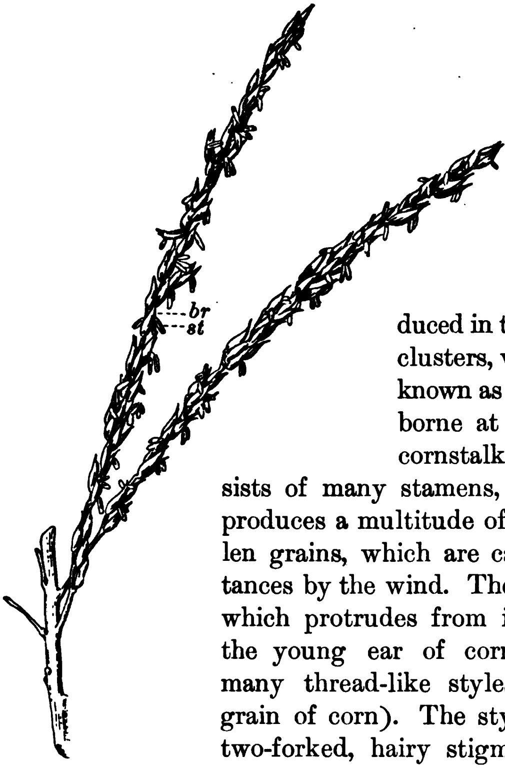


FIG. 126. Part of a corn tassel (staminate flower cluster)

br, a bract; *st*, stamens. One half natural size

136. Corn; pollination by wind. Indian corn affords an admirable example of pollination effected by aid of the wind. The pollen is produced in the staminate flower clusters, which are commonly known as the *tassel* (fig. 126), borne at the summit of the cornstalk. Each cluster consists of many stamens, and every stamen produces a multitude of dry, dust-like pollen grains, which are carried for long distances by the wind. The familiar corn silk, which protrudes from inside the husk of the young ear of corn, is composed of many thread-like styles (one from each grain of corn). The styles terminate in a two-forked, hairy stigma (fig. 127 *C*, *st*). The brush-like character of the protruding stigmas makes them very efficient in catching flying pollen grains.

If the pollen from a corn plant is shaken down upon the stigmas of the same plant, self-pollination only is effected and poor seed results. If the pollen which pollinates an ear comes from another corn plant, cross-pollination is effected and good seed results. Figure 159 shows the difference in growth between plants produced in the next generation from the two kinds of seed.

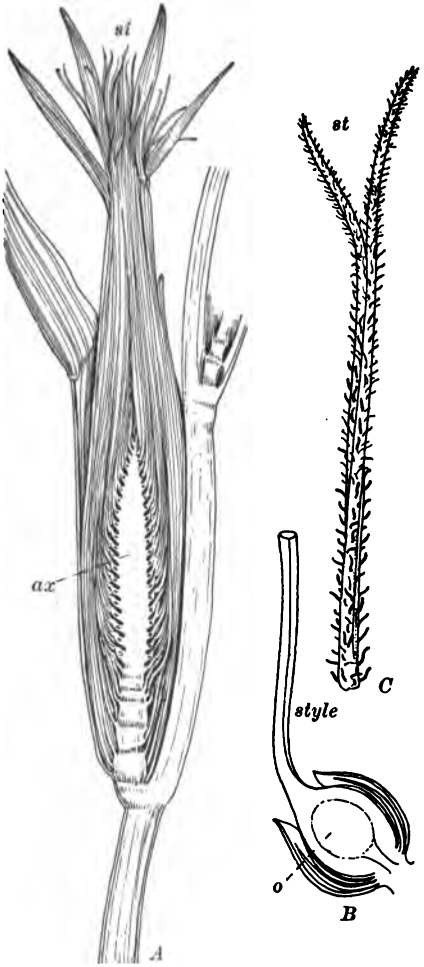


FIG. 127. Structure of an ear of corn (pistillate flower cluster)

A, section of young ear before fertilization of the ovules (grains); *ax*, axis of spike (cob); *si*, ends of silk (styles and stigmas); *B*, magnified section through a grain, showing bracts around the ovary, the ovule (*o*), and the base of the style; *C*, upper portion of style, with the stigmas (*st*) considerably magnified. After F. L. Sargent

137. The potato and the grape; flowers open to all insect visitors. The potato is a familiar example of a flower with wide-open corolla (fig. 128), easily entered by any kind of insect. The flowers, with their white corollas and conical group of yellow anthers, are moderately conspicuous and are visited by insects for the sake of the pollen which they afford. They yield no nectar.

The flowers of the grape are small and greenish. The corolla does not expand but falls off in one piece as soon as the flower is mature. This leaves the stamens and pistil exposed to all kinds of insect visitors. Insects of various kinds are attracted by the sweet odor of the flowers, and find plenty of nectar on the nectar glands which stand almost under the ovary between the bases of the filaments (fig. 120).

138. The periwinkle; a flower with concealed nectar. The common periwinkle,[1] a familiar old-fashioned flower, is an excellent illustration of one way in which nectar is concealed and protected from undesirable insect visitors. The tube of the corolla is moderately long and is partly closed by a sort of disk-shaped enlargement of the style (fig. 129). Part of the under surface of the disk does the work of a stigma.

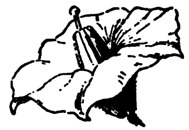


FIG. 128. Flower of potato, with widely expanded corolla

The disk is surrounded by gummy material and bears a crown of hairs at the top. The anthers open inward and so fill the crown of hairs with pollen. The long, slender tongue of an insect visitor (fig. 130), in being thrust through the fringing hairs and down the tube in search of nectar at its base, becomes covered with pollen. In this way some of it will be left on the stigma of the next periwinkle flower visited, which will secure cross-fertilization.

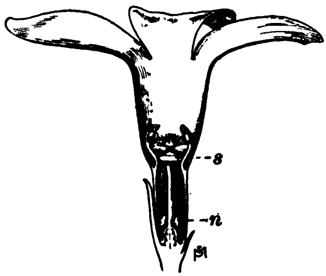


FIG. 129. Lengthwise section of flower of periwinkle (*Vinca minor*), the corolla with a closed throat and with the nectar not accessible to most small insects

s, disk-shaped expansion of the style, stigmatic on its lower surface; *n*, nectar glands at the base of the ovary

Many other instances of concealment of the nectar supply can be discovered by the observing student. One of the most obvious is in such flowers as snapdragon and butter-and-eggs, in which the two-lipped corolla is rather firmly closed, so that it can only be pried open by a moderately strong insect.

There is a large class of flowers in which the nectar is not so much concealed as out of the reach of ordinary insects, since it is at the bottom of a long and narrow corolla tube or in a slender spur of the corolla. Excellent instances of this are found in the flowers

[1] *Vinca minor*.

of the evening primroses, honeysuckles, and Jimson weeds (fig. 131). The nectar from such flowers can best be reached by insects with a very long proboscis, like that of the butterflies or the hawk moths (fig. 131). Many flowers with long corolla tubes are also visited by humming birds.

Red-clover flowers are pollinated mainly by bumblebees. What effect upon the crop of clover seed have field mice, which destroy the nests of bumblebees? How would red clover thrive if introduced into a country where there were no bumblebees?

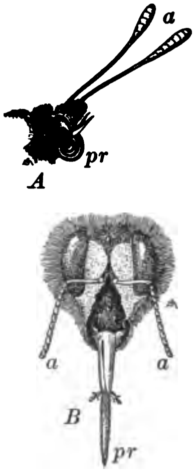


Fig. 130. *A*, head of cabbage butterfly; *B*, head of honeybee

a, antennæ; *pr*, proboscis, or sucking organ. The proboscis of the butterfly is represented as coiled into a spiral. Both somewhat magnified. After Behrens

Fig. 131. Pollination of flower of Jimson weed (*Datura*) by a hawk moth

The nectar is inaccessible to ordinary insects

139. The arum; a pitfall flower cluster. Our common jack-in-the-pulpit is the most familiar American member of the great (mostly tropical) Arum family. The over-arching hood and the tube from which it springs inclose a club-shaped axis on which are borne many inconspicuous flowers. Great

numbers of gnats or midges are attracted to the flower cluster and do not easily find their way out of the chamber in which it is inclosed, but when they do escape, carry pollen with them to the next jack-in-the-pulpit which they visit, and pollinate the flowers there.

The flower cluster of the common European arum[1] has been so much more carefully studied than that of our related American plant, and is so much more successful in detaining pollinating insects, that it is worth while to describe it in some detail. The chamber which surrounds the flower cluster appears to be moderately open, and admits the free entrance and exit of small insects. The *spadix*, or floral axis, bears several rows of downward-pointing bristles (fig. 132, *B*). Small midges are attracted to the interior of the flower chamber by its peculiar ammonia-like smell and by its warmth, which is considerably greater than that of the outside air. The midges readily crawl down through the palisade hairs, often bringing with them pollen with which they have become dusted in other arum-flower clusters. As they crawl down the spadix they pass over the immature staminate flowers (fig. 132, *B*) and

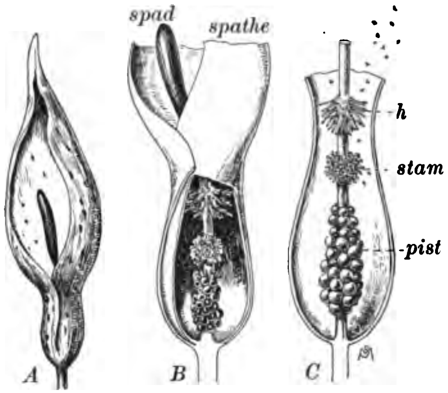


FIG. 132. Pitfall flower clusters of the European arum

A, exterior view of the flower cluster, about one third natural size ; *B*, the same drawn to a larger scale, with part of the covering removed ; *C*, part of *B*, drawn to still larger scale, with the flowers more mature and the hairs (*h*) withering and allowing the escape of imprisoned midges; *spad*, spadix, or floral axis; *spathe*, the hood covering the axis; *h*, hairs closing narrowed part of spathe; *stam*, group of staminate flowers (not mature in *B*, mature in *C*); *pist*, group of pistillate flowers (just matured in *B*, pollinated and developing seeds in *C*). *A* and *B*, after H. Müller

[1] *Arum maculatum.*

then reach the mature pistillate flowers which they pollinate. On attempting to fly out of the flower chamber they find it impossible to get through the fringe of hairs. After a time (often a few days) the stigmas wither, and in place of each a drop of nectar appears, on which the insects feed. At length the staminate flowers mature and allow a considerable quantity of pollen to fall to the bottom of the chamber. The insects crawl about in this, become thoroughly dusted with it, and finally, as the palisade hairs wither and droop, escape and fly away to another blossoming arum plant, and cross-pollinate its flowers in turn. The number of insect visitors to a single flower cluster is enormous, about four thousand midges being found in one flower chamber.

FIG. 133. The common milkweed (*Asclepias syriaca*)
Photograph by Jesse L. Smith

140. The milkweed; a pinch-trap flower. The milkweeds[1] are admirable instances of what are called pinch-trap flowers. There are more than twenty kinds of milkweed in the central and northeastern states, the commonest in many portions of the country being the one shown in figure 133. The flowers, of peculiar form (fig. 134, *A*), are borne in clusters. The general structure of the flower can be understood from figure 134, *A* and *B*. The detail of its structure that is of most interest in the study of modes of pollination is the way in which the pollen is borne. Each of the five anthers produces two rather large pollen masses. Between each pair of anthers is

[1] *Asclepias* and *Acerates*.

found a body shaped somewhat like a grain of wheat (fig. 134, *C* and *D*). This body, the *corpusculum*, is attached at each side to one pollen mass of each of the two adjacent anthers (fig. 134, *B* and *C*). Along the corpusculum runs a slit which gradually narrows toward the upper end and thus acts as a clip, holding firmly any small object that is drawn into it. As the exterior of the flower is smooth and slippery, the only way in which an insect can hold itself in place upon it is by inserting its claws in the slit of a corpusculum. When the insect

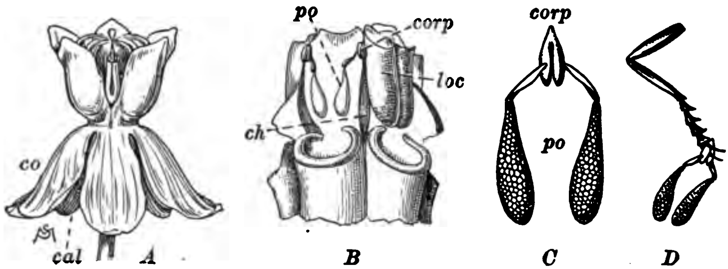


FIG. 134. Flower of the milkweed (*Asclepias*)

A, general view ; *B*, side view of flower after removal of the sepals, petals, and nectar-bearing organs ; *C*, pollen masses with attached clip ; *D*, pollen masses with clip attached to foot of a bee; *cal*, calyx; *co*, corolla ; *ch*, stigmatic chamber, inside of which is the stigma ; *corp*, *corpusculum*, or body to which the pollen masses are attached, acting as a clip; *loc*, locule, or pollen chamber of anther; *po*, pollen mass. All somewhat enlarged. *A* and *C*, after Prantl; *B*, after Herman Müller ; *D*, after Kerner

attempts to fly away, it drags the corpusculum and attached pollen masses with it, suspended by one or more claws (fig. 134, *D*), or sometimes it is held fast and dies. Hairy insects, like bumblebees, often carry away many pollen masses on the hairs of the under surface of the body (fig. 135). If the insect escapes from the flower and visits another, when it thrusts its foot through a corpusculum slit of the second flower the pollen masses already attached to the foot become torn away. The pollen masses thus detached are left in contact with the stigma of the second flower, and in this way most effectively secure cross-pollination.

The strong odor of many kinds of milkweed flowers and the abundance of nectar which they afford bring them many insect visitors. On the flowers of one common milkweed [1] in a single locality one hundred fifteen kinds of insect visitors have been found, including bees, wasps, flies, butterflies, and beetles.

141. Insects as carriers of pollen. Most flowers which require or are benefited by cross-pollination, and which are not wind-pollinated, depend upon insects as pollen carriers. It is not an over-statement to say that, in general, flowers seem to have acquired their odors and their colors (other than green) as means of attracting insects which may serve to cross-pollinate them. Insects vary greatly in their efficiency as pollinators; the small ones with smooth surfaces on the head, legs, and abdomen (such as ants and many beetles) carry little pollen, while bees, moths, and butterflies often carry considerable quantities. As already suggested, insects are led to visit flowers in order to get pollen or nectar. Almost any insect can obtain pollen from flowers of the ordinary type, but the nectar seekers are frequently provided with a very long sucking tube, or proboscis. The honeybee (fig. 130) and the sphinx, or hawk, moth (fig. 131) are good examples of nectar-sucking insects; and the sphinx, with its slender sucking tube, often many inches in length, is especially well equipped for getting nectar from narrow corolla tubes. Cucumbers grown under glass afford a good practical illustration of the importance of insect visits; it is found necessary to keep hives of bees in the cucumber houses in order to insure pollination, fertilization, and consequent crops of cucumbers.

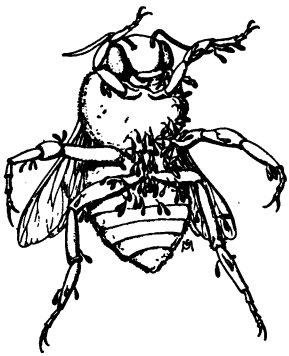


FIG. 135. Under surface of body of a bumblebee, to the hairs of which many pollen masses of green milkweed (*Acerates*) are clinging

After Robertson

[1] *Asclepias verticillata.*

An idea of the number of insect visits made to some flowers may be gathered from the fact that in a single locality one hundred kinds of insects have been seen to frequent dandelion flowers. The statistics in regard to visitors to the flowers of yarrow, Canada thistle, and the willows are fully as remarkable.

142. Odors of flowers as attractions to insects. It is evident from familiar facts that many insects have an acute sense of smell. The way in which flies are attracted by decaying meat or fish, and bees and wasps by a cider press at work or by fruit-preserving operations, is a matter of common observation. A single cluster of carrion-scented flowers has been known to attract carrion flies and dung beetles from a distance of hundreds of yards. Some flowers, such as those of the Virginia creeper (*Psedera*), the Dutchman's-pipe, the blueberries, and many others, are so inconspicuous that apparently their numerous insect visitors must be attracted by an odor which is almost or quite imperceptible to us.

It seems certain that the odors of flowers have been developed with reference to the sense of smell in animals (usually insects), and that these odors serve as a most efficient means of securing insect visits.

It is a most interesting fact that many flowers give off their scent mainly at the time of day when the insects which pollinate them are most active. Thus, some catchflies, the petunias, some kinds of tobacco, and several honeysuckles have little odor by day but are very fragrant at night, when the moths which pollinate them are on the wing. On the other hand, many plants of the Pea family, which are pollinated by day-flying bees and butterflies, give off their scent mostly by day, and especially in strong sunshine.

143. Colors of flowers as attractions to insects. There has been much discussion among botanists as to how far insects are led to visit flowers by displays of color. It appears to be fairly certain that no insects can make out the forms and sizes of objects at a distance of more than six feet, and that many are unable to see clearly even two feet. In spite of this, however,

it seems probable that the colors of flowers are an important means of attraction for many flower-frequenting insects.[1]

The commonest method of color display is that in which the color (other than green) is mainly found in the corolla, as in the flowers of the poppy, rose, sweet pea, and morning-glory. Sometimes the calyx also is bright-colored, or, as in the *Hepatica*, the *Anemone*, and the *Clematis*, the corolla is wanting and the showy calyx looks like a corolla. Not infrequently the display is all made by an enlarged and conspicuous set of specialized leaves (*bracts*) surrounding the flower, as in the flowering dogwood and many euphorbias (fig. 67), or even by highly colored ordinary leaves, like those of the poinsettia.

FIG. 136. Dichogamous flowers of plantain (*Plantago lanceolata*)

A, earlier stage, pistil mature, stamens not yet appearing outside the corolla; *B*, later stage, pistil withered, stamens mature. Six times natural size

144. Prevention of self-pollination; *dichogamy*. Of course, diœcious flowers, like those of the willow, cannot be self-pollinated. In the culture of date palms it is usual to pollinate the pistillate flowers by hand. Monœcious flowers, like those of Indian corn (figs. 126 and 127) are likely to be pollinated with pollen from another plant. As regards bisexual flowers, it is evident that there are many opportunities for self-pollination; but in all cases in which cross-pollination produces more seed or stronger plants, or both, it is clear that anything in the structure or mode of development of the flower which tends to secure cross-pollination is highly advantageous. One

[1] See Kerner-Oliver, Natural History of Plants, Vol. II. Henry Holt and Company, New York. Also Knuth-Davis, Handbook of Flower Pollination, Vol. I.

of the most effectual means of preventing self-pollination in bisexual flowers is the maturing of the stamens at a different time from the pistils; this is known as *dichogamy*. In some flowers, as in the figwort and some plantains (fig. 136), the pistils mature first. In such cases the pollen from older flowers (in the staminate condition) is transferred to the stigmas of recently opened flowers (in the pistillate condition).

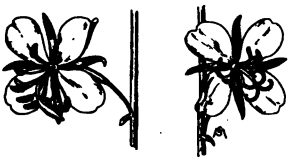


FIG. 137. Dichogamous flowers of fireweed (*Epilobium*)

At the left, earlier stage with stamens mature but the stigmas united into a club-shaped mass. At the right, later stage with stamens withering but the stigmas spread apart and ready for pollination

Usually, as in some mallows and in the gentians and fireweeds (*Epilobium*) (fig. 137), the stamens mature first. An insect visitor to a newly opened flower in the staminate condition becomes somewhat covered with pollen. Then, flying to an older flower in the pistillate condition, the insect is almost sure to leave pollen on the stigmas and thus insure cross-pollination.

It is common to find the stamens of a flower maturing a few at a time, as in "nasturtium," buckwheat, and many other flowers. This gives more opportunities for insects to carry away the pollen than would be possible if it all matured at once.

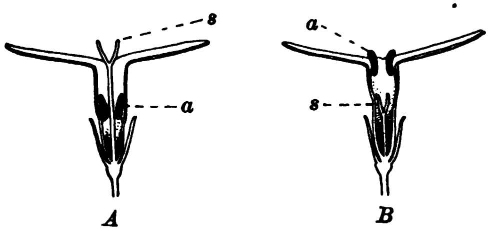


FIG. 138. Lengthwise section of dimorphous flower of bluets

A, long-styled form; *B*, short-styled form; *a*, anthers; *s*, stigmas. About 3 times natural size

145. Prevention of self-pollination; *dimorphism*. A means of preventing self-pollination which is even more effective than dichogamy is found in the structure of flowers in which some have a long pistil and short stamens, others a short pistil and long stamens. This condition

occurs in the flowers of bluets (fig. 138), the partridge berry, the primrose, and some other common flowers. It is easy to see that the tongue of an insect smeared with pollen by contact with the anthers of figure 138, *A* would just come into contact with the stigma of *B*, and that the insect's abdomen covered with pollen in *B* would just touch the stigma of *A*. All the flowers on an individual plant are of one kind (either long-styled or short-styled), and the pollen is of two sorts, each kind sterile on the stigma of any flower of similar form to that from which it came.

On the general subject of pollination of flowers and illustrations of special cases see

DARWIN, The Effects of Cross- and Self-Fertilization in the Vegetable Kingdom. D. Appleton and Company, New York.

DARWIN, Different Forms of Flowers on Plants of the Same Species. D. Appleton and Company, New York.

DARWIN, The Various Contrivances by which Orchids are fertilized by Insects. D. Appleton and Company, New York.

GRAY, Structural Botany. American Book Company, New York.

KERNER-OLIVER, Natural History of Plants, Vol. II. Henry Holt and Company, New York.

KNUTH-DAVIS, Handbook of Flower Pollination. Clarendon Press, Oxford.

WEED, Ten New England Blossoms. Houghton Mifflin Company, Boston.

PROBLEMS[1]

1. Of what use to the plant are flowers? On what grounds would you decide which of two flowers serves this purpose more effectively?

2. In a general way, are the flowers discussed in the earlier or the later sections (sects. 130–145) more perfectly equipped for successful pollination?

3. If the lowest types of flower came earlier than the highest ones, what kind of pollination probably characterized some of the first flowering plants that appeared on the earth?

4. Why does a corn plant growing alone seldom produce good ears?

[1] These problems are to some extent based on the statements in regard to floral structures given in Chapter IX.

5. Some willows, as the common yellow willow (*Salix alba*, var. *vitellina*), are usually represented in this country only by pistillate trees. Can they bear seed? Can they be reproduced?

6. Of the various methods by which self-pollination is rendered difficult, — unisexual flowers borne on the same plant, unisexual flowers borne on different individuals, dichogamy, dimorphism, — which is the least effective? Which is the most effective? Give as many instances as you can of plants which exemplify each method (not citing any of those mentioned in this chapter).

7. Describe as well as you can the qualifications of each of the following flowers for securing pollination: hazel, birch, box elder, buttercup, nasturtium, horse-chestnut, dandelion, locust, sweet pea, primrose.

8. Explain why the subject of pollination is an ecological one. Can you give any reasons why plant ecology is one of the most difficult divisions of the science of botany?

9. Give some practical applications of the principles of pollination to agriculture and horticulture.

CHAPTER XI

FRUITS; SEEDS AND SEEDLINGS; SEED DISTRIBUTION

146. Origin of the fruit. As already suggested (sect. 127), the ovary, after fertilization, enlarges and develops into some kind of seed-containing structure. An apple, a bean pod, and a tomato are good examples of matured ovaries (with or without the addition of other parts) serving to contain the seeds, and each is botanically termed a fruit. Most of the fleshy portion of the apple is derived from the enlarged receptacle and calyx, though a little of it about the core comes from thickening of the walls of the carpels. The papery chambers of the core, with the contained seeds, are the most important portion of the apple for reproduction; that is, for growing new apple trees. A ripe bean pod with its seeds is a dry fruit resulting from the maturing of a one-loculed ovary and its contents; a ripe tomato is a fleshy fruit resulting from the maturing and extensive thickening of a two-to-several-loculed ovary and its contents.

147. Kinds of fruits. The various types of fruits have been carefully classed for purposes of scientific study and description, but in an elementary book it is not worth while to give much space to an account of these classes.[1] The fruits most important for human food are the *grains* — dry fruits with the ovary wall so closely adherent to the seed that the whole is usually taken for a seed. *Nuts*, such as the beechnut, hazelnut, chestnut, and acorn, are hard, dry, one-seeded fruits, most of them larger than grains and resulting from the ripening of a several-loculed ovary only one chamber of which

[1] Some of the principal types of fruits are admirably described in Gray, Structural Botany. American Book Company, New York.

matures. *Berries*, as the botanist understands the term, are generally fleshy fruits resulting from the development of a several-loculed ovary. The grapefruit, lemon, orange, grape, persimmon, and tomato are true berries, though not usually called by that name. On the other hand, a blackberry or a raspberry (fig. 139) is not a genuine berry but a group of fleshy ripened carpels attached to the surface of a large receptacle, and a strawberry is a group of little dry carpels embedded in a large, juicy receptacle. Pomes (apple and pear) have the seeds inclosed by the ripened and fleshy ovary wall, which may itself be inclosed by ripened and fleshy floral structures outside of it. Drupes (peach, apricot, and plum) have the seed inclosed by the ripened ovary, part of which has become hard and part of which is fleshy.

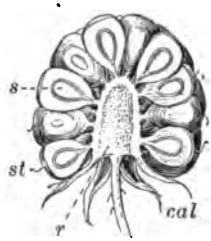


FIG. 139. Lengthwise section through a raspberry

The fruit consists of a cluster of little stone fruits, each of which has much the structure of a plum or a cherry. Every stone fruit is a ripened carpel. *cal*, calyx; *r*, receptacle; *st*, remains of style and stigma; *s*, seed

148. Form and structure of seeds. Something has already been said (sect. 13) of the earliest stages in the formation of seeds. In the present chapter a very brief account of their structure and mode of growth will be given, together with a few words in regard to the ways in which they are dispersed.

A very little observation suffices to show how greatly seeds differ in size and shape. It would not be possible to estimate accurately, without measuring both, how many times larger a lima bean is than a poppy seed; and there are some orchids whose seeds are not a hundredth as large as a poppy seed, while the coconut is vastly larger than any kind of bean. In form seeds vary from nearly spherical ones, like those of mustard and radish, to such thin, flattish seeds as those of milkweed and catalpa.[1]

[1] The student should notice that many objects commonly called seeds, such as those of parsnip, lettuce, and dandelion, are not merely seeds but fruits.

The internal structure of seeds differs greatly in the various kinds. Some contain no separate parts that can be readily made out. Many kinds, however, consist of

1. An *embryo*, or miniature plant.
2. Some plant food stored elsewhere than in the embryo. This is usually called *endosperm*.[1]
3. A seed coat or coats.

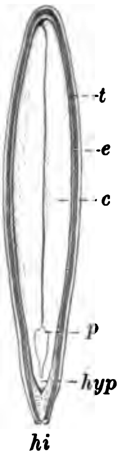


FIG. 140. Lengthwise section of squash seed

hi, hilum, or scar, marking place of attachment to the ovary; *hyp*, hypocotyl; *p*, plumule; *c*, cotyledon; *e* (innermost layer next to cotyledon), endosperm; *t*, testa. Two and one-half times natural size

Frequently the embryo is found to have a fairly well-defined set of organs: the *hypocotyl*, or little stem; the *cotyledons*, or seed leaves; and the *plumule*, or seed bud.

149. Classification according to number of cotyledons. The seeds of one great division of seed plants, the *monocotyledons*, comprising grasses, sedges, palms, lilies, and many other groups, have one cotyledon. As shown in figure 158, *B*, the reserve food is stored mainly outside the embryo.

The seeds of the other and still larger division, the *dicotyledons*, have two cotyledons (figs. 141 and 144). The plant food in the seeds of dicotyledons is often stored in the embryo itself (figs. 140 and 141), as in the chestnut, hazel, beech, oak, pea, bean, squash, and sunflower; or often between or around the cotyledons of the embryo, as in the buckwheat, four-o'clock, castor bean, honey locust, and morning-glory (fig. 144).

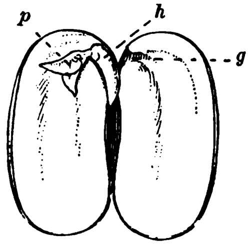


FIG. 141. A common bean split open, after soaking in water

h, hypocotyl, lying on one of the cotyledons; *g*, groove in the other cotyledon, where the hypocotyl lay; *p*, plumule

[1] Reserve food that was formed outside of the embryo sac is called *perisperm*.

150. Kinds of plant food found in seeds. All seeds contain some protein material, though frequently it is present only in small quantities. Carbohydrates (in the form of starch, sugar, and cellulose) and fats or oils also occur. Many other substances, such, for example, as the poisonous compounds that occur in the seeds of larkspur and Jimson weed, and in the castor bean, the opium poppy, and nux vomica (out of which strychnia is made), are characteristic of certain seeds.

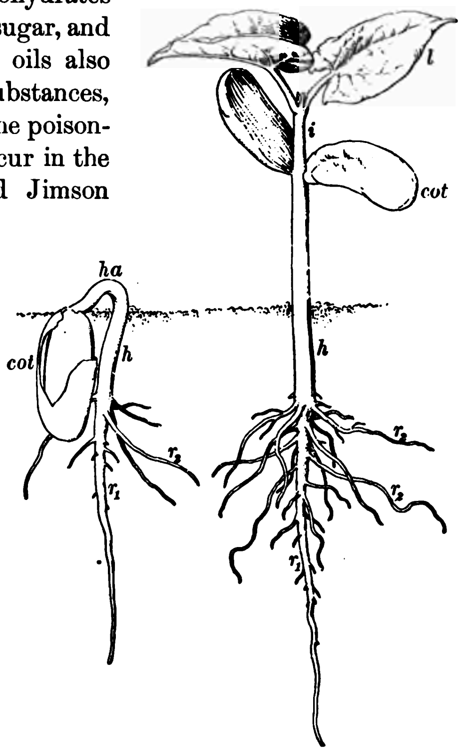


FIG. 142. Two stages in the growth of the bean seedling

In the younger stage the arch of the hypocotyl is but little above the surface; in the older stage the cotyledons have separated, the first internode has elongated considerably, and the first pair of foliage leaves has expanded. *cot*, cotyledon; *h*, hypocotyl; *ha*, hypocotyl arch; *i*, internode; *l*, leaf; r_1, taproot, which proceeded from the tip of the hypocotyl; r_2, branches of r_1. Natural size

The reserve protein is indispensable, since it is the basis of protoplasm, without which life cannot exist nor growth take place. Other reserve foods serve mainly to supply building material for the plant body until it can draw raw materials freely from the soil and the air and carry on photosynthesis for itself. For this purpose the rice grain supplies mainly starch; the Brazil nut, oil; the grain of Indian corn, both starch and oil; and date seeds or coffee seeds, cellulose. Of the substances mentioned proteins,

starch, and oil are highly valuable for human food, and so is sugar, which occurs in small quantities in all the bread grains and in considerable amounts in the best varieties of sweet corn.

The selection and cultivation of plants like the grains, which contain much digestible food in a concentrated form, and which may retain their food value for some years with little loss, marked a long step upward in the civilization of the human race.

151. The seed coat. The seed coat is more or less efficient in protecting its contents from mechanical injury, such as crushing, and in many cases it protects the more perishable materials within it from decay. Before germination can begin, a certain amount of moisture must usually soak into the seed, either through the general surface, as in most seeds, or, in such hard-shelled seeds as the coconut, hickory nut, walnut, and butternut, through a thin or soft place in the wall. Usually the little opening in the ovule, known as the *micropyle* (fig. 119, *m*), remains in the seed and serves to admit moisture.

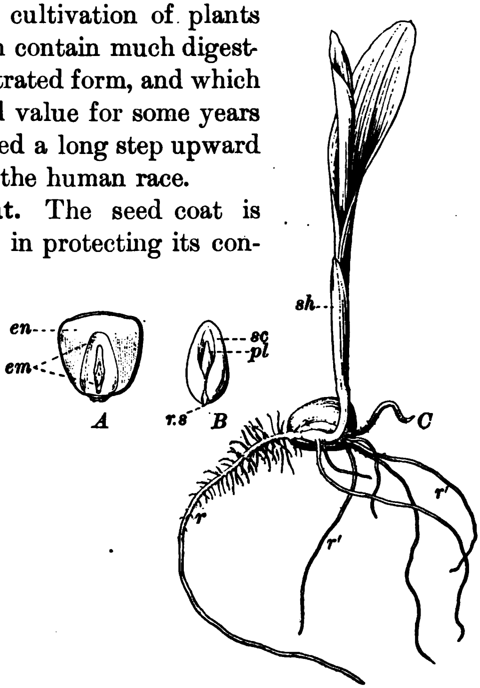


FIG. 143. Grain and seedling of corn

A, lengthwise section of grain; *B*, the embryo removed; *C*, seedling; *en*, endosperm; *em*, embryo; *r.s*, sheath covering tip of rudimentary root; *sc*, scutellum, or absorbing cotyledon; *pl*, plumule; *sh*, sheath-like leaf in which the first foliage leaves are inclosed; *r*, first root, springing from within *r.s*; *r'* later-formed roots arising from other parts of the grain

The coats of many seeds have wings or outgrowths of hairs which aid in their dispersal. Other modifications in the coats

of seeds apparently serve, in some cases, as aids in their dispersal and in others as means of preventing the seed from being eaten by animals.

152. Conditions for germination. A sound, live seed will germinate, or sprout, when suitable conditions are present. The requisites for germination are

1. Proper temperature.
2. Enough moisture.
3. Air or oxygen.[1]
4. Seed coats permeable to air and moisture.

The temperature most favorable to germination varies with the kind of seed; for any given kind there seems to be a lowest limit, a most favorable (*optimum*) temperature, and a highest limit.

Wheat and barley, for example, will sprout at temperatures but little above the freezing point, though they succeed best at about 84° F. Muskmelons and cucumbers sprout at 60° F. but begin much more promptly at temperatures of 93° and upward.

Most farmers have learned by experience that the temperature requirements are not the same for all kinds of seeds. All know, for example, that if corn is planted before the ground is warm enough, it will decay and have to be replanted, but that peas can be sown very soon after the frost is out of the ground.

There is moisture enough in a few kinds of seeds, like those of the willow and the poplar, to allow them to begin to germinate as soon as they are ripe; but most seeds need to be supplied with moisture from without. Too little moisture causes them to germinate very slowly, as is often noticed during spring droughts, while immersing them in water causes many kinds to rot because the air supply is not sufficient.

The germination of seeds planted too deep in clay soils is very likely to be hindered by lack of air. In warm, open soils there is usually air enough; the danger here is that the seeds may dry up because of too shallow planting.

[1] Some seeds begin to germinate without air, but soon die unless it is supplied to them.

153. Rest period before germination. A few kinds of seeds may sprout as soon as they are ripe; most kinds need a period of rest and comparative dryness before they will grow. The

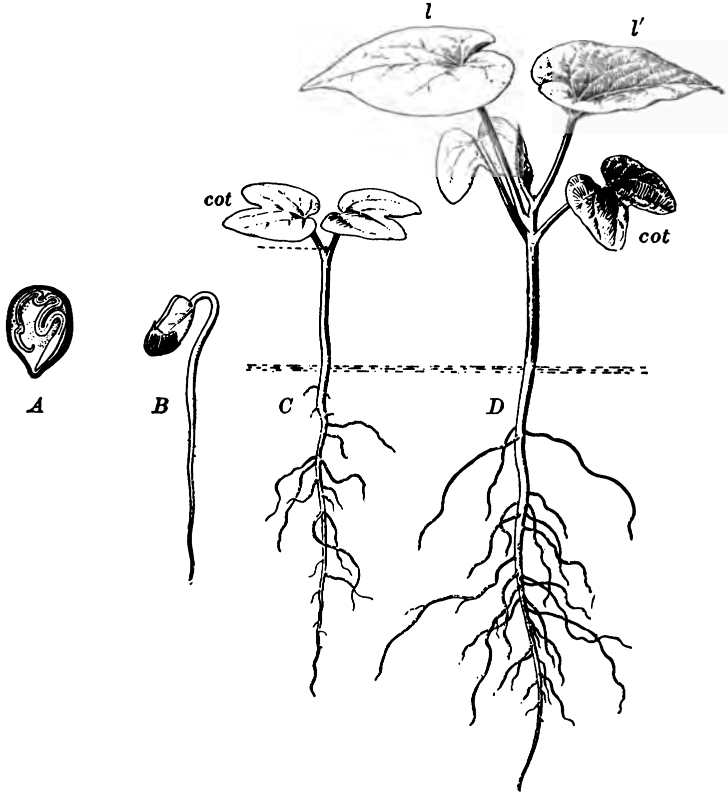


FIG. 144. Seed and seedlings of morning-glory

A, section of seed, showing cotyledons folded together and inclosed in endosperm; *B*, seed germinating, the taproot descending and the cotyledons pushed up out of the ground; *C*, seedling with cotyledons expanded, the plumule showing as a bud at the junction of their leafstalks; *D*, seedling further developed; *cot*, cotyledons; *l*, first ordinary leaf; *l′*, second ordinary leaf

importance of drying seeds is well shown in the case of corn. Kiln-dried corn has, in one instance, been shown to yield sixteen bushels per acre more than air-dried seed of the same variety.

After the rest period the time required for germination varies greatly. Grains, grasses, and many seeds of herbs of the Pea family germinate in from two to eight days, and seeds of most plants of the Parsley family in about fourteen days. The seeds of the hornbeam and ash are said not to grow until the second spring after they are planted.

154. Seed testing. In growing crops from the seed it is desirable to use only seed of the highest quality. The seed should be of one of the best varieties, that is, a choice kind of grain, beet, tomato, or other plant, which is adapted to the soil and climate of the region.[1] Good seed is *pure* and of high *vitality*. Purity means freedom from earth, sticks, broken seeds, bits of leaf, or weed seeds. High vitality means a large percentage of vigorous live seeds which, under good conditions, will grow. The purity can be tested by examining a small average sample of the seed with a good lens and separating the sound seeds of the desired plant from foreign seeds and other impurities. The vitality can be tested by sprouting a convenient number of seeds, one lot from each sample to be examined. Place the counted seeds on moistened blotting paper in a plate and cover them with an inverted plate. If many seeds fail to grow, it is because (1) the seeds have been kept too long and have lost their vitality; (2) the seeds have been exposed to too great heat or moisture, or to too sudden changes in temperature; (3) the seeds were immature or otherwise imperfect when collected. The use of impure seeds or those of low vitality is extravagant, no matter how cheaply they were bought, as impure seeds may introduce many bad weeds, and seeds of low vitality will not give a good stand of the grain or other crop planted.[2]

[1] See Chapter XII.

[2] The teacher can usually secure a bulletin on seed testing from the agricultural experiment station of his state.

See also Lyon and Montgomery, Examining and Grading Grains, Ginn and Company, Boston; Burkett, Stevens, and Hill, Agriculture for Beginners, Ginn and Company, Boston; and Warren, Elements of Agriculture, The Macmillan Company, New York.

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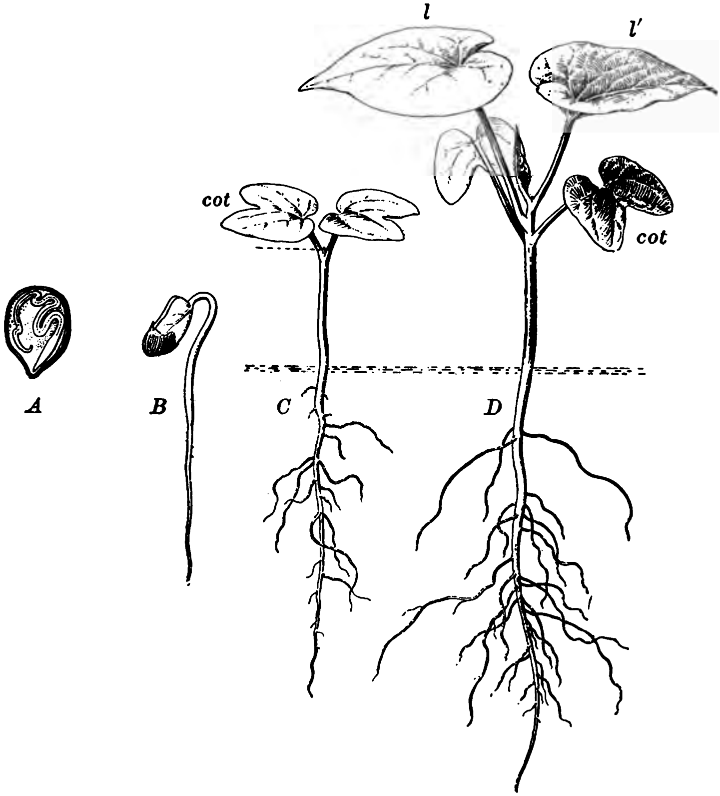

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155. Types of seedlings. Seedlings[1] may be divided into two groups, *monocotyledonous seedlings* and *dicotyledonous seedlings*. Those of the dicotyledonous group may be further subdivided into plants with *underground cotyledons*, as the pea and the oak, and those with *aboveground cotyledons*, as the maple, bean, squash, and morning-glory (fig. 144).

The monocotyledonous seedling may or may not raise its single cotyledon out of the ground after germination. The onion does so, but the grains do not. In all the larger grains (as in corn) the fitness of the plumule for piercing hard clods or bits of sod is very noticeable and frequently serves the plant well in breaking its way out of the ground.

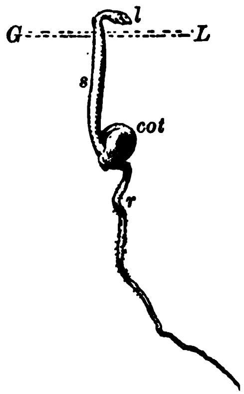


FIG. 145. Pea seedling
cot, the unopened cotyledons; *GL*, ground line; *r*, root; *s*, stem; *l*, rudimentary leaves. One half natural size

Dicotyledonous seedlings with underground cotyledons, like the pea (fig. 145), are better able to force their way out of the ground, if planted deep, than are most of those with aboveground cotyledons, like the bean. Therefore even large seeds of the latter type, like those of the bean, melon, cucumber, and squash, should not be planted deep. Very minute seeds, like those of the portulaca, poppy, and most plants of the Pink family, should be planted on the surface of well-raked, fine earth and then barely covered by sifting over them a little of the finest loam or by dragging a trowel or other suitable implement lightly back and forth over the bed.

156. What becomes of the cotyledons. In the seeds of many monocotyledons, as in the grains and in date seeds, the cotyledon is merely an absorbing organ; it remains within the seed and serves to remove liquefied plant food from the endosperm and transfer it to the growing embryo. In such dicotyledonous seeds as those of the pea, horse-chestnut, and buckeye,

[1] Not considering those of coniferous shrubs and trees.

the cotyledons remain underground, inclosed in the seed coats, and gradually empty their stores of reserve food into the growing seedling. In the bean the cotyledons come out of the ground but never become leaf-like, while in the squash, castor bean, buckwheat, and morning-glory (fig. 144) they emerge from the ground and become short-lived leaves.

FIG. 146. Pea seedlings growing in water

A, deprived of both cotyledons; *B*, with cotyledons uninjured

157. Reserve food of seeds digested by enzymes. One of the most surprising things about the early growth of seedlings is the rapid way in which many kinds begin to grow even in sawdust or on moist blotting paper. Evidently the plant food must all come from the seed in the beginning, and the removal of most of the reserve food of the seed greatly retards the growth of the seedling (fig. 146). It is not at once clear how the proteins and the starch of some seeds and the oil or cellulose of others are so quickly withdrawn from them and transferred to the growing plantlet. Most of the reserve substances found in seeds are difficultly soluble or quite insoluble in water or the watery sap of plants, but the insoluble substances, before being transferred into the seedling, are transformed into soluble ones. This is due to the action of certain substances known as *enzymes* or *soluble ferments*. An enzyme as found in seeds is a substance secreted

by the plant for the purpose of digesting or rendering soluble such plant foods as require digestive action before they can be absorbed by the tissues of the young seedling.

The most familiar case of action of enzymes on a large scale is the malting of barley, in which the starch of the grain is converted into a sugar by diastase. It is said that diastase can change ten thousand times its own bulk of starch into sugar.[1]

158. Propagation due to seeds. Annual plants evidently owe their continued existence to the growth of new crops from the seed. If every grain of Indian corn in the world were to be consumed during some winter, corn plants could not again be grown. Many bulb- and tuber-bearing perennials could continue to propagate their kind for an indefinitely long period without seeds. Some herbs, such as the common field sorrel, and many shrubs and trees, such as rosebushes, black locusts, and silver-leaved poplars, reproduce themselves abundantly by buds formed on the roots, but most trees, and especially nearly all conifers, such as the pines, spruces, and firs, are usually propagated only by seeds.

People in general hardly recognize the wonderful capacity of seeds for carrying on plant life under extremely adverse conditions. Most flowering plants soon die if they are entirely deprived of water for a few days; darkness is fatal to them and very low temperatures kill many kinds of plants in a few minutes; but the seed may be kept for months or years without water, in absolute darkness and at the lowest temperature ever encountered on the earth's surface, and yet remain ready to grow as soon as it is exposed to conditions favorable to germination.

159. Need of seed dispersal. The successive crops of farm and garden annuals are secured by careful seed planting in prepared soil. The seeds of wild plants are also sown, on a still more extensive scale, by natural agencies. In any country the relative numbers of most kinds of wild seed plants

[1] On digestion and enzymes consult J. R. Green, An Introduction to Vegetable Physiology, Chapter XVI. P. Blakiston's Son & Co., Philadelphia.

usually remain from year to year without great changes except those which are brought about by human interference. This fact is evidence enough that seeds in unimaginable numbers must be scattered in such a way as to make good the losses in the plant population of the world due to all destructive causes. The means by which this distribution of the seeds is secured will be taken up in sections 162 and 163.

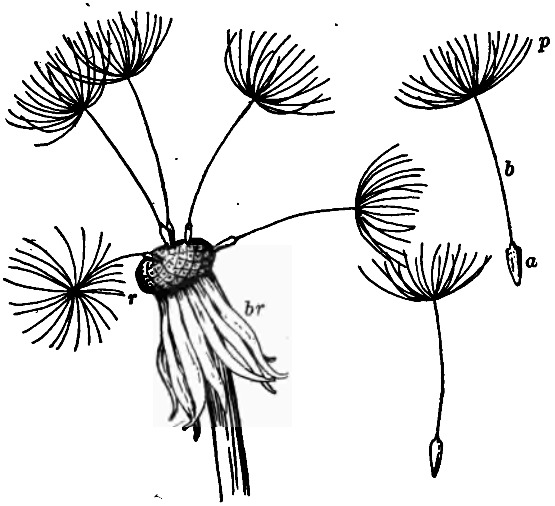


FIG. 147. Dandelion fruits

a, achene; *b*, beak of pappus; *br*, bracts; *p*, pappus (representing the limb of the calyx); *r*, common receptacle for all the fruits. Twice natural size

160. The struggle for existence. Only a small proportion of all the seeds annually produced can have a chance to grow. The resulting contest among plants for a foothold and for the means of subsistence forms one portion of what the great English naturalist, Charles Darwin, called *the struggle for existence.* It is shown by careful calculation that about 5,300,000 acres of land could be sown with the wheat grown at the end of fifteen years from a single parent kernel, if every grain were to grow and live. But the wheat plant does not produce a very large number of seeds. The so-called Russian thistle

(*Salsola Kali*, var. *tenuifolia*), a most troublesome weed, bears from 20,000 to 200,000 seeds. Taking the moderate estimate of 25,000 seeds to a plant, and supposing all of these seeds to grow into plants equally productive, the offspring of the 25,000 individuals would number 625,000,000, and the next generation would number 15,625,000,000,000. Supposing

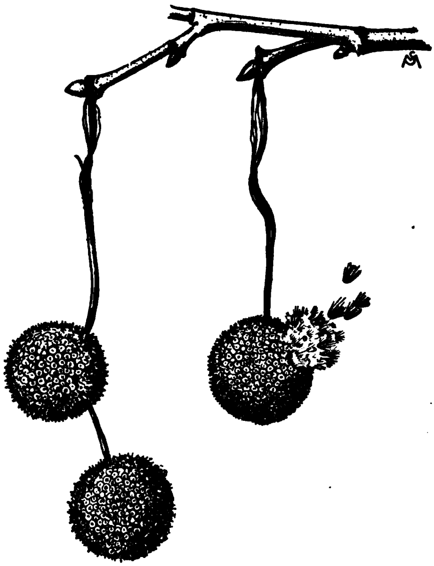


FIG. 148. Globular clusters of fruits of the sycamore in late March

The cluster at the right is broken, and single fruits are being carried off by the wind

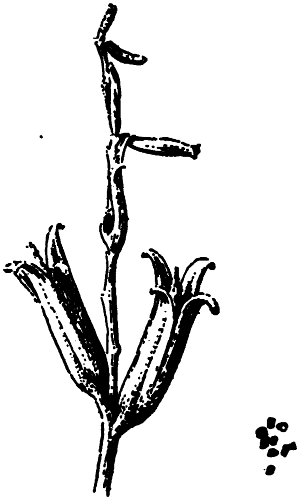


FIG. 149. Pods of evening primrose

The open top allows the seeds to escape gradually. Three fourths natural size

each plant to have a diameter of about 3 feet and to occupy an area of 7 square feet, the student can readily calculate how many square miles of territory the number of plants last named would cover if actually in contact with one another.[1]

[1] To the teacher: If the class will carefully count and estimate the number of seeds produced by some common weeds, and then calculate the number of their possible descendants in the course of five or ten years, the computation will prove most instructive.

Evidently no kind of flowering plant actually increases at any such rate as has just been suggested, or it would soon crowd most others out of existence. The means by which the unlimited multiplication of any one species is prevented are lack of extremely rapid and thorough means of disseminating the seeds, multiplication of the insect and plant enemies of the species (a factor which is often not very important), and over-crowding or competition with other plants of the same or of different species.

FIG. 150. Cockleburs

This troublesome weed often grows along a path, where men carry the seeds back and forth in their clothing, and animals in their hair or fur

161. Competition as a check on increase. No one can realize just what competition among plants means unless he makes some careful out-of-door studies of plants growing under conditions of great overcrowding. A portion of a grainfield too thickly sown, a very weedy bit of garden soil left to itself for the whole growing season, or a piece of recently cleared forest in which coppice growth is starting from old stumps, or where seedling trees are springing up in great numbers — any one of these will teach a most important lesson. The writer has found wild-black-cherry seedlings, to the number of more than 100 to the square foot, beginning to grow in the spring under a large wild-cherry tree. As the parent tree was in thrifty condition and its top was nearly 30 feet in diameter, there might have been some 70,000 seedling cherries every year killed by crowding and shade under this one tree, although, in fact, there were never so many as this.

Competition sometimes results in killing outright most of the competing plants; sometimes it only renders them dwarfish and incapable of producing many flowers or seeds.

The means by which the successful individuals weaken or kill their neighbors are mainly

1. Overshadowing, resulting in deficient photosynthesis in the shaded plants from lack of light.
2. Robbing the defeated plants of water.
3. Robbing them of soluble salts, such as nitrates and phosphates of the soil.

FIG. 151. Fruit of the wild black cherry, a very valuable timber tree

The seeds, which are hard and indigestible, are disseminated mainly by birds. One half natural size

The deprivation of sufficient water and salts interferes with the nutrition of the overcrowded plants and may soon stop their growth.

162. Mechanisms for distributing seeds. Many seeds, such as those of the catalpa, the milkweed, and the willow, have wings or tufts of down which insure their being carried considerable distances by the wind. Tufted fruits, such as those of the thistle and the dandelion (fig. 147), are familiar to most people. Sometimes the plant retains the seeds or fruits for months after they are ripened, and thus secures their gradual dispersal. The globular clusters of fruits of the sycamore (fig. 148) remain on the tree during the entire winter—many of them even till the new crop of leaves has appeared in the spring.

Frequently the pod, or capsule, is so constructed that it opens at the top (fig. 149) and scatters seeds whenever it is swung to and fro by the wind or jostled by a passing animal.

Fruits, clusters of fruits, and plants full of fruits are rolled along the ground (especially over the snow) by the wind, often for great distances, scattering seeds as they go. If it is a whole plant that travels, or a large part of a plant, it is known as a tumbleweed. Such are the Russian thistle (*Salsola*), tumble-mustard (*Sisymbrium*), winged pigweed (*Cycloloma*), ghost-plant (*Amaranthus*), and the fruit cluster of old-witch grass (*Panicum*); the white-pine cone is an example of a single fruit traveling in the same way.

Fig. 152. Red raspberry bush in fork of a maple

Many aquatic plants, as grasses, rushes, sedges, water dock, lotus, bur reed, and a multitude of other species, have fruits or seeds which float, often for long distances, and then lodge and grow.

Burs of many kinds (fig. 150) lodge in the hair, fur, or feathers of passing animals and are finally dislodged in various distant places where they may grow.

163. Dispersal of edible seeds. Edible seeds and fruits (such as nuts, the grains, and berries) and stone fruits (like plums and cherries) are frequently swallowed by animals and later voided undigested and in a condition to grow. In this way wild cherries (fig. 151) and wild apples are planted about pastures and in open woods. Also, raspberry, currant, and gooseberry bushes, asparagus, and bittersweet may be found growing in the forks of trees (fig. 152). Squirrels, blue jays, and some other animals carry away nuts and bury them, often leaving them to grow the following spring.[1]

[1] On the general subject of seed dispersal see Kerner-Oliver, Natural History of Plants, pp. 833–877, Henry Holt and Company, New York; also Beal, Seed Dispersal, Ginn and Company, Boston.

PROBLEMS

1. Show how widely the botanist's use of the term *fruit* differs from that of people who are not botanists. Make out a list of some common articles of food that are properly classed as fruits though not sold under that name.

2. Show that many young seedlings live on the same kind of vegetable food that human beings eat. Is this true of a very young date palm?

3. How would you perform a series of experiments to discover the optimum temperature for germination of the seeds of agricultural plants? What precautions would you need to take?

4. If the prices of very low-grade red-clover seed and of high-grade seed are respectively $5.20 and $15.00 per bushel, but only 18 per cent of the poor seed germinates, while 96 per cent of the good seed germinates, which is more expensive to use? If the poorer seed contained 26 per cent of weed seeds and the better quality was practically pure, how would this affect the question as to which kind is more economical? Get some clover seed and test it to see what percentage of it will grow.

5. State some reasons why better results are obtained by sowing large, plump seeds of any kind of grain or other annual plant than by using small, shrunken seeds.

6. A pound of red-clover seed contains about 300,000 seeds. Frequently 15 pounds to the acre (43,560 sq. ft.) are sown. How many plants to the square foot might such a sowing produce? Does this number seem too large or too small properly to cover the ground? Is it, then, a waste of seed to sow 15 pounds per acre? Explain.

7. How long would most useful plants of the farm and garden maintain themselves if left to grow unaided among their wild competitors? What instances of this have you ever seen?

8. What are some of the plants which first spring up where a piece of woodland has been cleared and the clearing burned over? Explain why these plants are among the first to establish themselves in such places.

9. Why are uncommon kinds of plants often found near wool-cleansing establishments?

CHAPTER XII

PLANT BREEDING

164. The basis of plant breeding. It is the business of the professional plant breeder to discover or originate desirable varieties of plants and then to perpetuate them. As soon as he becomes certain that he has obtained a really valuable new variety, he proceeds to multiply it until he can offer to growers everywhere its seeds, bulbs, or other means of reproducing it.

The possibility of producing new varieties rests largely upon two highly important facts:

1. *That all the higher plants vary from generation to generation.*
2. *That the higher plants sometimes mutate.*

Variations are familiar enough to every observing person. No two corn plants, bean plants, or tomato plants are just alike, even though they may have been grown from seed from the same ear, the same bean pod, or the same tomato. The variations may be noticed in the root, stem, leaf, flower, or fruit, or in several or all of these. The term *mutation* is less commonly used than the term *variation.* It is the scientific name for the kind of abrupt appearances of forms, extremely unlike the parent, long known to horticulturists as *sports.* A single bud upon a peach tree may mutate and produce a branch which will bear nectarines, and a bud upon a tree which bore purple plums has been observed to grow into a branch which bore only yellow plums of a kind previously unknown. Some of the most valuable varieties of the grains are seed sports, or mutations first noticed in the seedling grown from the seed of a very different variety.

165. Unit characters.[1] Much more definiteness has recently been given to the discussion of questions relating to plant breeding by the introduction of the idea of *unit characters.* Every species or variety of animal or plant is considered by many authorities to be composed of a set of unit characters, or simple features by which it is distinguished from other species or varieties. Just what this statement means will appear more clearly if some of the unit characters which belong to different varieties of a familiar species of plant are set down. In the case of timothy, our most important grass for haymaking, twenty-eight opposing character pairs have been noted. Some of these are

Heads
- Long or short
- Continuous or interrupted
- Large-seeded or small-seeded
- (and 8 others)

Leaves
- Long or short
- (and 4 others)

Stems
- Tall or short
- Many or few branches from the base of the stem
- (and 4 others)

Nodes
- Near together or widely separated
- (and 2 others)

Habit characters
- Inclined to blow down or remaining erect
- Rusting readily or rust-resistant
- Early or late maturing

Careful breeding would probably soon give a variety with any one of these twenty-eight characters strongly marked, and several of them could be combined in a single variety if desired.

[1] See the valuable summary of this subject, given by Professor Herbert J. Webber in his address before the American Breeders' Association, *Science*, April 19, 1912.

166. Selection of desired characters. Of course the practical plant breeder would concern himself only with the characters of timothy which affect its value for haymaking or for a pasture grass. For haymaking he would try to get a combination of characters which would give abundant leaves, stems branching freely from the base, and heads and seeds large enough to insure good reproduction. A single plant of a good type will yield about five times as much hay as one of a poor type like that which is shown in the upper part of figure 153.

FIG. 153. Variation in timothy

The two lower plants are of the same age and from the same seed, growing side by side in the field. The one at the left is a dwarf; the one at the right a large and desirable type. The one in the upper part of the figure is a dwarf plant with very large heads — an undesirable type, from its scanty leafage and few stems. Photograph by New York Agricultural Experiment Station

To do successful work in plant breeding, one of the first requisites is trained observation — ability to recognize the appearance of any valuable character or group of characters in growing plants. A skilled botanist once found twenty-three kinds of wheat growing in a field where the grain was supposed to be all alike. One of these kinds was isolated and became the parent of an excellent variety that has been extensively cultivated for about a century. The Concord grape sprang from a seedling of one of the common wild grapes of New England. Its originator failed to get another important new variety from among 22,000 seedlings that grew from Concord seeds. One of the most valuable blackberries of the low-growing (dewberry) type, the Lucretia, is a variety found growing wild upon a West Virginia plantation during the Civil War. The well-known Wealthy apple originated as a seedling discovered after ten years of seed planting and the use of much more than a bushel of apple seeds.

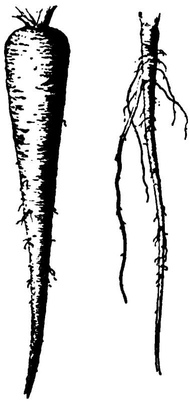


FIG. 154. Effect of cultivation on the parsnip

The parsnip at the left is a cultivated one; that at the right, a wild one at the end of the first season's growth. One eighth natural size

167. The perpetuation of desirable varieties. In the case of shrubs or trees which can readily be grafted or budded (sect. 87), or in plants like the potato, the canna, or the gladiolus, which can be propagated by tubers and bulbs, it is easy to perpetuate any new variety. If it is necessary to reproduce the plant by means of seed, it may be found that the desired variety always "comes true"; that is, reproduces itself with little or no perceptible change, as is the case with the established varieties of the grains (sect. 171). On the other hand, the plants may tend to "run out"; that is, to revert to the average original type from which the selected variations have been developed. Sugar beets are particularly troublesome

in this respect, so that it is sometimes necessary to select only about one best beet out of every thousand to grow seed for the next crop.

In the case of plants grown for the production of seed of standard varieties for the market, as beans, peas, or any of the many flowers (such as sweet peas), in regard to which there is much competition, great attention is paid to weeding out and destroying plants that do not conform to the standard. This process is called *roguing.* The maintenance of the breed depends largely upon the intelligence and thoroughness with which it is carried out.

168. Ancient and modern plant breeding. No one knows when plant breeding began, because the earliest attempts of man to cultivate useful plants date back to unknown antiquity, and it is highly probable that the first growers of plants for human food more or less unconsciously selected the best seeds to be sown for a new crop, and were thus really practicing plant breeding. Among the Chinese, agriculture began at least 4600 years ago, and for a considerable part of that time they have paid much attention to the perpetuation of desirable varieties of the plants of the farm and garden.

Modern plant breeding did not begin at any definite date. Some valuable work was done in selecting and propagating improved varieties of wheat in Great Britain as early as the first quarter of the nineteenth century, but it was not until toward the middle of the century that many investigators began to try to put plant breeding on a scientific foundation, working with plants ranging all the way from the cereals to sugar beets. One of the main problems in plant breeding is that of predicting the way in which the characters of a plant will be inherited by its descendants. In a large number of cases, a number which is rapidly increasing, it is possible to make such predictions with scientific accuracy. These are based on the immense mass of data which has been gained from tens of thousands of experiments made by scientific investigators and by practical plant breeders everywhere.

The best way in which to illustrate what modern plant breeding means is to give a few instances of the methods actually employed.

169. Wheat breeding: its purpose. Wheat is the most important grain for human food in temperate climates, and North America is by far the greatest wheat-producing region in the world. The annual value of the crop of the United States ranges from $250,000,000 to $500,000,000. Scientific wheat breeding began barely a century ago, and has progressed more in the United States since 1890 than during all our previous history.

Some desirable qualities to be sought in wheat breeding are (1) large yield per acre; (2) good quality for bread-making, requiring a high per cent of the tenacious *gluten*, the main protein portion of the grain; (3) hardiness, shown in winter wheat, in resisting severe winter conditions; (4) resistance to rust; (5) resistance to drought.

Not all of these qualities can be combined in the highest degree in any one variety, and therefore every region should grow the particular kind of wheat best suited to the local conditions and market. About eight species of wheat are recognized, and the number of varieties of these species is very large.

170. Wheat breeding: the method. In order to show how carefully the process of wheat breeding is managed in our best agricultural experiment stations, the principal steps of the operation are here given in the barest outline, omitting many most important details.[1]

1. Ten thousand large, sound kernels of a single good variety of wheat are selected and planted in hills, and each hill is numbered. About 95 per cent of the poorer plants are rejected as they mature. When mature, the heads of each of the chosen plants are put together in an envelope and preserved.

[1] See *Bulletin 62*, University of Minnesota Agricultural Experiment Station, and *Bulletin 29*, Division of Vegetable Physiology and Pathology, U.S. Dept. Agr.

When thoroughly dry, the product of each plant is weighed, and only a few of the heaviest groups of heads are kept for seed.

2. The second year about a hundred of the seeds of each mother plant are planted in a group (hundred-group or *cent-gener*). To each such group is given a special designating number. Heads of several of the best plants in each hundred-group are reserved for seed. The total produced by each hundred-group is weighed. This enables the experimenter to estimate the comparative value of the mother plants.

3. The third year the process of the second year is repeated.

4. The fourth year the same process is repeated.

5. The fifth year the most promising varieties are planted in small fields in the ordinary way. Those varieties which yield abundantly in the field and turn out well in the milling tests which are applied to the harvested grain, are distributed among farmers for seed wheat.

A new variety can soon be introduced over an immense territory. It is estimated that in fifteen years from the time of planting one seed its descendants might be made to cover more than 5,000,000 acres of wheat fields.

Wheat breeding is still making such rapid progress that at present it is not possible to say how much the quality and quantity of our wheat crop may yet be improved by the introduction of better varieties. The total number of acres in the United States differs considerably from year to year. It seems likely, as a rule, to exceed 45,000,000.[1] The average yield ranges between 10 and 15 bushels per acre, although it is possible, with the most improved seed on the best soils, to raise more than 40 bushels per acre.[2] Choice of the best seed would undoubtedly increase the average yield 5 or more bushels per acre. It is easy to see how important a gain this would be if it were calculated in terms of the current price of wheat.

[1] See Carleton, "The Future Wheat Supply of the United States," *Science*, August 5, 1910.

[2] See Hopkins, Soil Fertility and Permanent Agriculture. Ginn and Company, Boston.

171. Principles upon which wheat breeding depends.[1] The work of the earliest breeders of wheat was not based on any general knowledge of the laws of plant variation and inheritance. The principles of breeding, as applied to the small grains, were first worked out by Professor W. M. Hays of the University of Minnesota Agricultural Experiment Station, and by Dr. Hjalmar Nilsson, director of the experiment station at Svalöf, Sweden. Some of the main principles upon which wheat breeding depends may be stated as follows:

FIG. 155. A hybrid wheat and the parent forms

The hybrid is in the middle. It is somewhat intermediate between the parents, being nearly (though not quite) beardless, like the right-hand parent, with a length of head intermediate between the two and with the grains and their covering bracts stout, as in the left-hand parent. Photograph by Minnesota Agricultural Experiment Station

1. Every species of cereal usually comprises many well-marked varieties, or, as they are sometimes called, *elementary species.* Sometimes several hundreds of these are included in each of the longest-cultivated species of grain; this is notably true in the case of wheat.

2. The varieties, while still growing in the field, may be distinguished by such botanical characters as the position, shape, size, and bearded or beardless condition of the head; the form, size, and appendages of the spikelets which it contains; and the size, shape, color, and hardness of the grain.[2]

[1] See De Vries, Plant Breeding. The Open Court Publishing Company, Chicago.

[2] The hardness cannot be accurately known until the grain is ripe and dry.

3. The varieties distinguished by such characters as are mentioned in the preceding paragraph often differ much in their economic value, which depends on such qualities as productiveness, resistance to drought, resistance to rust, and the grade of flour which they produce.

4. Varieties usually come true from the seed, so that, when one has been chosen and isolated, it may be grown indefinitely with little change.

172. Variation in corn. Indian corn is preëminently an American plant. At the time of the discovery of America,

FIG. 156. A prize ear of Johnson County White corn[1]
An admirable type of dent corn. Photograph by L. B. Clore

and probably for a long period before that time, it was grown by the Peruvians, by the Mexicans, and by many tribes of Indians. It is supposed to have originated in South America or Central America, near the west coast. Varieties of corn differ greatly in size (from 1½ to 22 feet high) and in the time required for maturing. Some corn in Paraguay is said to ripen in one month, while Illinois field corn requires from four to five months.[2]

[1] This ear of corn was bid in by the grower (Mr. Clore) at an auction sale of exhibits at the Chicago National Corn Exposition in October, 1907. The price paid was $250.

[2] See *Bulletin 57*, Office of Experiment Stations, U.S. Dept. Agr., 1899.

Six well-defined types of corn are recognized, but only four are of much economic importance. These are *pop corn*, with small kernels and with endosperm all or nearly all horn-like; *flint corn*, with much horn-like endosperm and a grain too hard to be fed to most animals without being ground; *dent corn*, with the kernels indented at the outer end; and *sweet corn*, in which most of the starch of the endosperm is replaced by a kind of sugar. Of these four kinds dent corn is by far the most important, constituting the great bulk of the crop in the corn belt. Each of the types of corn has many varieties; of dent corn alone more than three hundred have been named and described. Most of these varieties are found to show slight variations, which make them more or less desirable for the corn grower, and his efforts must be directed mainly toward improving the quality of existing kinds.

173. Qualities sought by the corn breeder.[1] Of the many qualities that may be sought by the corn grower four of the most important are (1) productiveness; (2) high percentage of proteins; (3) high percentage of oil; (4) low percentage of oil.

With reference to (1) it suffices here to say that the average yield of corn for the entire United States, according to statistics for 1908, was a little over 26 bushels per acre; for the New England States, with soil no better than the average, and with a poorer climate, it was 40.5 bushels; and for some New England growers it was 100 or more bushels per acre. No small part of the difference between the average 26-bushel yield and the 100-bushel yield depends on the choice of seed, though cultivation and soil are also important factors.[2]

[1] See *Bulletins 55, 82, and 87*, Illinois Agricultural Experiment Station.

[2] See *Massachusetts Crop Report*, May, 1910.

Throughout the Southern states and elsewhere boys' corn clubs are coming to be extensively organized. The object of these clubs is to grow more and better corn by choice of the best seed and by thorough cultivation. In the State Corn Club Show held at Atlanta, Georgia, in December, 1912, there were exhibits made by 70 boys who had each grown 100 or more bushels of corn to the acre. The state record for a boy's crop (raised at a profit) is held by Ben Leath, of Kensington, Georgia, who in 1911 grew 214 bushels and 40 pounds of corn on one acre, at a net profit of $182.60. See *Bulletin 175*, University of Georgia.

Greatly increased care in its selection would probably at once add more than $100,000,000 to the annual value of our corn crop. The structure of the grain of corn, as shown by the diagrams in figures 157 and 158, is such that the relative amounts of proteins, starch, and oil can be roughly estimated by a mechanical examination of the grain. This most important fact was discovered by Professor C. G. Hopkins, of the University of Illinois. The proteins are very largely stored in the horn-like part of the endosperm (fig. 157, *p*), and in the embryo; the starch is mainly found in the white, floury part of the endosperm (*s*); and the oil is nearly all in the embryo (*e*). If seed corn is chosen from ears with kernels in which the horn-like portion is highly developed, the result will be a crop with a large percentage of proteins; seed corn with large embryos will yield a crop rich in oil, and seed corn with small embryos a crop poor in oil.

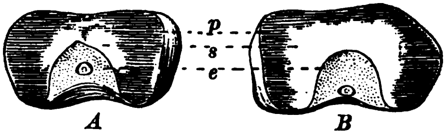


FIG. 157. Kernels of corn with high and with low percentage of proteins

A, high proteins, *B*, low proteins; *p*, horny layer, consisting largely of proteins; *s*, white starchy portion; *e*, embryo. After *Bulletin 87*, University of Illinois Agricultural Experiment Station

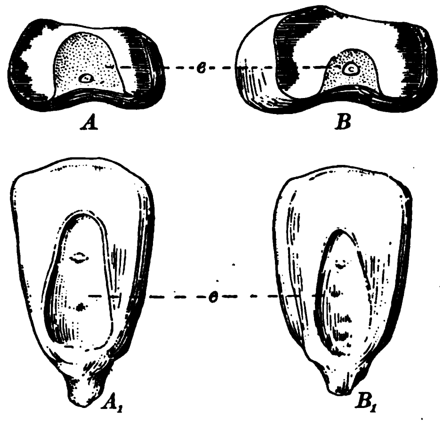


FIG. 158. Kernels of corn with high and with low percentage of oil

A, A_1, cross section and face view of high-oil kernels; B, B_1, cross section and face view of low-oil kernels; *e*, embryo. Most of the oil (as well as a good deal of the proteins) is contained in the embryo, so that an embryo large in proportion to the size of the kernel means a high percentage of oil in the grain. After *Bulletin 87*, University of Illinois Agricultural Experiment Station

Corn with high proteins is especially valuable as a food for man and the lower animals, since the most serious fault found with corn as a cereal food is its low percentage of proteins compared with its oil and carbohydrates. Corn with high oil value is especially desired by the glucose manufacturers, since they also manufacture corn oil, which is the highest-priced component of the grain. Corn with a low percentage of oil is in demand for feeding hogs for bacon, especially for exportation. It has been found possible, at the University of Illinois Agricultural Experiment Station, to breed low-protein corn with an average percentage of 6.7 proteins, and high-protein corn with an average percentage of 14.4 proteins. At the same station the average low-oil corn contained 2.5 per cent of oil, and the high-oil corn 7.0 per cent. The process of selection must be kept up, for the variations thus obtained are not permanent varieties.

174. Method of corn breeding. In a general way it may be said that the method of breeding corn is based on the same principles as those adopted for wheat and other cereals. There are, however, many variations in details, some of the most important depending on the fact that the plants should be pollinated with pollen from other individuals, but that these should, so far as possible, be all of the same stock. It is not sufficient that all should be of the same variety; the most rapid progress will be attained if all the parent plants are descended from the same ear of corn.

It will not be necessary to give in detail all the methods followed in the selection of seed and the precautions taken to prevent mixture of varieties in the growing crop. Successful corn breeding demands

1. The choice of the most desirable known variety as a basis for breeding for any given purpose.

2. The selection *in the field* of well-matured ears from the best plants.

3. Growing trial rows the next season from the ears mentioned in paragraph 2, each ear planted in a row by itself.

Every other row should be detasseled, to prevent the plants from pollinating their own ears, and seed ears should be saved only from the detasseled rows.

4. The continuation, during subsequent seasons, of the process of seed growing from the best plants obtained by the process of paragraph 3.

In beginning to breed corn it is better to use seed obtained from the locality in which the experiment is to be made; that

FIG. 159. Cross-pollination and self-pollination

The effect of cross-pollination and of self-pollination on the growth of corn from the seed. The two rows of small plants at the left grew from seed produced by self-pollination, the larger plants of the other rows from seed produced by cross-pollination. Photograph furnished by Funk Bros. Seed Co.

grown under decidedly different conditions may not succeed. If high-oil or low-oil corn, or high-protein or low-protein corn, is desired, the ears used for seed must be carefully chosen with reference to the development of the horn-like endosperm or of the embryo (figs. 157 and 158). Selection in the field, as mentioned in paragraph 2, is necessary in order to make sure that the ears chosen grew on vigorous plants and that ears from the same plant are kept together. If detasseling is

not thoroughly carried out, much self-pollination and self-fertilization is sure to occur. Corn which is self-fertilized produces smaller and less vigorous plants the next season than cross-fertilized corn (fig. 159). Detasseling has therefore been found to increase the yield of corn more than ten bushels per acre.[1]

175. Williams's method. The method of corn breeding as above outlined has been criticized on the ground that little or no attention is paid to the productiveness of the plant used as the source of pollen. A new system devised by Professor C. G. Williams, of the Ohio Agricultural Experiment Station, provides for equally careful selection of the staminate and pistillate parents. The system in its barest outlines, as stated by Professor Williams, provides for

1. The usual ear-row test. Only a portion (usually about one half) of each ear is planted. The remnant is carefully saved, and when the ear-row test has shown which ears are superior, recourse is had to the remnants to perpetuate these ears in a later season.
2. An isolated breeding plot in which are planted the four or five best ears as demonstrated by 1. *Not the progeny* of the best ears, but the *original ears*. Usually the best ear is used for staminate plants and planted on each alternate row in the small breeding plot. All the plants from the other ears going into the plot are detasseled.

The pedigreed strains produced in the breeding plot are multiplied for general field use and also furnish ears of varying worth for a second ear-row test, if it is desired to continue the improvement.

The ear-row test need not be isolated, for no seed is taken from it. Neither is there any need for detasseling until the breeding plot is reached.

176. Hybridizing. As has already been shown (sects. 13 and 127), seed production is the result of fertilization of the egg within an ovule by a pollen grain. Usually the pollen and the ovule concerned in fertilization are derived from plants of the same species. Often pollen of another species is

[1] For details about corn breeding see De Vries, Plant Breeding, The Open Court Publishing Company, Chicago; *Bulletin 100*, Illinois Agricultural Experiment Station; and *Circular 66*, Ohio Agricultural Experiment Station.

of no use in fertilizing, but sometimes it succeeds perfectly,[1] as when pollen from one species of plum is used for pollinating flowers of another species, or when one parent flower is a plum and the other a cherry, or one a plum and the other an apricot. Any plant grown from seed thus produced is called a *hybrid.* The terms *hybrid* and *hybridization* are also coming to be generally used in cases of breeding between varieties as well as between species. *Crossing* is another term used instead of *hybridization*, and the result of the process or hybrid is called a *cross.*

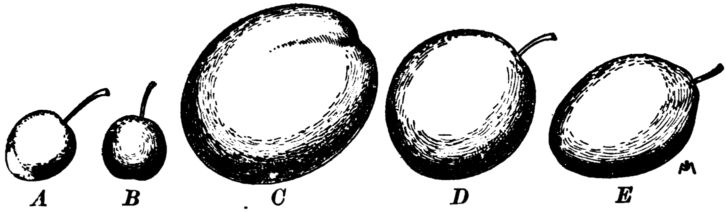


FIG. 160. Results of hybridizing plums

A, a stoneless wild plum; *B*, *C*, *D*, *E*, fruits of seedlings obtained by crossing *A* with the French prune. About one half natural size. Modified from a photograph by Burbank

Hybrids are often extremely variable (figs. 160 and 161), and for this reason it has become a common practice to hybridize plants for the sake of getting a variety of new combinations of characters in the hybrid seedlings, and then to select the desirable kinds for breeding purposes. Until recently it was supposed to be impossible to predict the way in which the characters of the parents would be inherited by the successive generations of hybrids. But a law known from its discoverer as *Mendel's law* often enables the breeder to foretell the characters which the hybrid plants will inherit. Gregor Mendel,

[1] The plants grown from seed which was the result of pollination between different species are often vigorous but incapable of producing seed. This sterility of plants bred by cross-pollination between different species is so common that it was formerly often used as a test to determine whether two kinds of plants that seemed to be different species were really such or were only varieties.

the first successful investigator of the mode of inheritance in hybrids, was an Austrian monk, who carried on his researches in his monastery garden for eight years and published his results in 1865. His discovery was little noticed for about thirty-five years, when it quickly became generally known to biologists everywhere. Mendel's law is not quite simple enough to be stated and illustrated in an elementary botany for secondary schools.[1]

177. How hybrids are artificially produced. Hybridizing, or crossing, plants, is sometimes an easy, sometimes a rather difficult, process. It is simplest in unisexual flowers — for example, in those of Indian corn. Here the tassel (fig. 126) is a

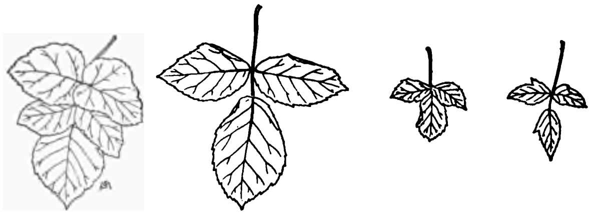


FIG. 161. A few of the many leaf forms of different hybrids between the blackberry and the raspberry

Modified after photograph by Burbank

cluster of spikes of staminate flowers, and the ear (fig. 127) is a spike of pistillate flowers, each thread of the silk representing a stigma and style attached to an ovary (grain of corn). In hybridizing corn it is only necessary to tie a paper bag over the ear before the silk appears, in order to keep off stray pollen, and leave it covered until full-grown, then remove the bag, dust the silk thoroughly with pollen from tassels of the desired crossing variety of corn, and thereafter keep the ear covered until the silk is entirely withered. Sometimes in hybridizing corn the stalks are detasseled just before the ears are ready to receive pollen. If all the stalks of one

[1] See R. C. Punnett, Mendelism, The Macmillan Company, New York. Also L. H. Bailey, Plant-Breeding, The Macmillan Company, New York.

kind or of one row are thus detasseled, it is made probable that pollen, if received at all by the ears of the detasseled stalks, must come from another row or from another kind of corn. The detasseling of alternate rows is a rather common way of insuring cross-pollination. In most cases of hybridizing with bisexual flowers it is necessary to carry out processes similar to the following ones:

1. Select the flower to be pollinated before it opens or before its own pollen is mature. If it is one of a cluster of flowers, as in the wheat and the apple, remove from the cluster of the flowers all that are not to be operated upon.

2. Open the remaining flowers and remove the stamens by taking hold of the filaments with fine forceps, or cut away all the stamens at once, as shown in figure 162. Keep the flower or the entire twig covered with a paper bag until the stigma is mature.

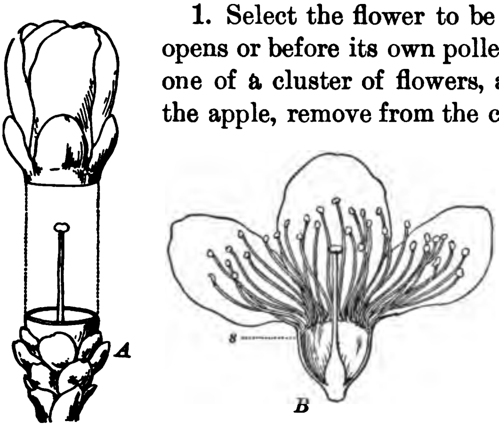


Fig. 162. A peach flower prepared for hybridization

A, flower cut round for removal of the stamens, with the removed parts of the young flower showing above; *B*, longitudinal section of a flower showing level (*s*) at which the cut was made in *A*

3. When the stigma is mature, pollinate it with the desired kind of pollen. This may be done with the finger tip or with a camel's-hair brush or other implement. It is safer to take pollen from a flower that has been kept covered with a paper bag to keep off foreign pollen.

4. Keep the pollinated flower covered with a paper bag until the fruit has grown considerably.

178. Plants grown from hybrid seeds. When seeds produced by hybridization are planted, the seedlings grown from them may vary greatly in their vegetative characters, as size,

habit of growth, and form of root, stem, or leaf (fig. 161). They may show much variation in the flowers or in the fruit (fig. 160). The physiological characters of the seedlings may vary greatly; that is, they may have very different periods of maturity and of hardiness in resisting drought, frost, or disease. If any of the characters of the hybrid are highly desirable, the breeder will try to perpetuate the type. If he is dealing with a plant like the potato or the bulb-bearing plants, which can be propagated by planting the tubers, bulbs, or similar parts, the effort to introduce the new variety will probably succeed; and it is not difficult to propagate new varieties of grapes by cuttings, and apples, pears, quinces, peaches, plums, and cherries by grafting or budding; but in the case of plants which must be grown from the seed the perpetuation of hybrid varieties is often difficult or impossible. Sometimes the seed of the hybrid seedling cannot be made to grow, and sometimes the plants will not come true from the seed, so that the promising hybrid variety is represented only by one plant, which leaves no descendants like itself. Professor L. H. Bailey, one of the highest authorities on plant breeding, has by crossing obtained about a thousand wholly new types of pumpkins and squashes, and never succeeded in perpetuating a single one.

179. Instances of successful hybrids. A few successful varieties of wheat and corn are the result of hybridization, and more may be expected in the future. Many good grapes are known to be hybrids, and so are probably a few of the best, like the Delaware and Catawba. Some good blackberries and many excellent plums have been obtained by hybridization. Citrous fruits have been successfully hybridized.[1] Many of our most ornamental flowers, especially varieties of *Canna*, *Amaryllis*, and *Gladiolus*, together with great numbers of orchids, are hybrids.

180. Some rules for plant breeding.[2] Neither the science nor the art of plant breeding can be taught wholly from

[1] See *Yearbook of the Department of Agriculture*, 1904.

[2] See L. H. Bailey, Plant-Breeding, Lecture III. The Macmillan Company, New York.

CHARLES DARWIN

Charles Darwin (b. 1809; d. 1882) for twenty-two years collected data upon problems of competition, variation, survival, and heredity; then (1858), together with A. R. Wallace (b. 1822; d. 1913), presented his essay, "Origin of Species, or Preservation of Favored Races in the Struggle for Life"; published his epoch-making book, "On the Origin of Species," in 1859, and afterwards published many volumes containing a great mass of data bearing upon the evolution of plants and animals. Darwin was an unsurpassed investigator; his rule of observing without prejudice and of adopting no conclusion except on a basis of observed facts, his fearlessness in following truth, his revulsion at known error, furnished an invaluable contribution toward the scientific method of study in biology

books. Careful study of the gardens or fields of some successful breeder is also necessary. The five rules which follow are here given only to illustrate some of the precautions necessary to insure success.

1. For breeding experiments choose plants like wheat, corn, and apples, which naturally show many varieties or elementary species (fig. 163).

2. Breed for one character at a time; that is, do not try to get such a product as a strawberry which shall surpass most others in size, sweetness, bearing qualities, and ability to stand shipping long distances — all the desirable qualities in one berry.

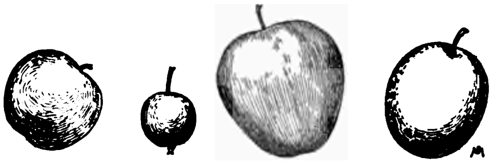


FIG. 163. Four extremely unlike varieties of apple selected from thirty-six varieties, all seedlings of the Early Williams apple

Modified from photograph by Burbank

3. Do not try to get opposite qualities in the same breed. For instance, corn cannot be bred for high percentage of starch and of protein at the same time.

4. Choose plants for seed by inspection as they grow in the field. A melon or a cucumber plant which bears many rather large fruits is likely to be a better parent than a plant which bore only one very large fruit. The total product of the individual should be ascertained by field study, and the vigor and general condition of the plant should be carefully noted.

5. Keep up the type by constant selection of the best individuals for seed, even after breeding has resulted in securing plants that come up to the desired standard. This is absolutely necessary in perpetuating, for instance, the variations which make the difference between the sweetest and the poorest sugar beets; but it is also useful in keeping such elementary species as wheat varieties up to the highest standard, because the seed of a desirable variety might be taken from imperfect or diseased ears and yield a poor crop.

COLLATERAL READING

The names Yearbook, *Farmers' Bulletin*, *Bulletin* . . ., Bureau of Plant Industry, as used in the list given below, all refer to the publications of the United States Department of Agriculture.

A very detailed list of books and articles on plant breeding will be found in Bailey, Plant Breeding. The Macmillan Company, New York. Some titles not already referred to in this chapter are as follows:[1]

General

Yearbook, 1898, "The Improvement of Plants by Selection."
Yearbook, 1906, "The Art of Seed Selection and Breeding."
Farmers' Bulletin 334, "Plant Breeding on the Farm."
Bulletin 167, Bureau of Plant Industry, "New Methods of Plant Breeding."
Cyclopædia of American Horticulture, article "Plant Breeding." The Macmillan Company, New York.
Cyclopædia of American Agriculture, article "Plant Breeding." The Macmillan Company, New York.
Davenport, The Principles of Breeding. Ginn and Company, Boston.

Special

Farmers' Bulletin 229, "Production of Good Seed Corn."
Yearbook, 1906, "Corn-Breeding Work at the Experiment Stations."
Yearbook, 1902, "Improvement of Cotton by Seed Selection."
Farmers' Bulletin 342, "Potato Breeding."

PROBLEMS

1. In which kind of plants — annual, biennial, or perennial — can plant-breeding results be most rapidly attained? Why?

2. In what kind of plants — those propagated by seeds or those propagated by vegetative means — are the results of plant breeding most readily perpetuated?

3. If you were asked to originate a new variety of string beans, how would you go to work?

4. Is plant breeding easier with plants that have many well-defined and permanent varieties or with those that have no such varieties? Illustrate.

[1] The number of valuable bulletins published by the agricultural experiment stations of the several states is so great that no attempt is here made to cite them.

5. Give examples of plants that "come true to seed" and of others that do not. How does this determine the mode of plant breeding necessary in each case?

6. How do you account for the fact that there are so many slight differences in long-known varieties of cultivated plants, as Baldwin apples, Crawford peaches, Bartlett pears?

7. In saving seed corn of a valuable variety, what can you do to keep the quality up to the highest point? Name several points to be attended to. Send to your state agricultural experiment station for reports upon the change in yield produced by proper selection of seed.

8. Why is it important for seed corn but not for wheat that plots of different varieties should be kept widely separated.

9. If you were to undertake to hybridize the following plants, which would be the easiest to manipulate and which the most difficult? Give reasons. Thistle (fig. 111), willow (fig. 105), arum (fig. 132), grape (fig. 120), corn (figs. 126 and 127).

10. If you succeeded in hybridizing two species of tulips, *A* and *B*, could you propagate the hybrid by planting the bulb matured during that season? Give full reasons for your answer.

CHAPTER XIII

HOW PLANTS ARE CLASSIFIED

181. Introductory. In preceding discussions we have often had occasion to speak of closely related plants which, while different in some ways, were sufficiently similar to enable us to recognize their likeness. Thus we speak of different kinds of grasses, different kinds of corn, or different kinds of oaks. Also, in actual practice many other bases of grouping are used, as is suggested when we speak of agricultural plants, tropical plants, desert plants, water plants, and poisonous plants. Similarity in structure offers a basis of classification that is commonly used. By means of this basis plants that resemble each other most closely are grouped together; then the groups having the closest resemblance are combined into a larger group, until finally all the larger groups compose the last and largest group — the plant kingdom.

182. Oaks as illustrations. A good illustration of the smaller groupings of plants may be had by referring to some of the common oaks. In various parts of the United States we find the white oak, bur oak, red oak, black oak, blackjack oak, live oak, and many others. There are certain special or specific differences between these oaks, as is shown by their acorns and leaves (fig. 164), and each specific kind of oak is called a *species* and has a species name, as *alba* (white), *rubra* (red), *macrocarpa*[1] (bur), etc. Furthermore, these and all the other species which we call the oaks are grouped together into one *genus* (or kind), the genus name of the oaks being *Quercus*. Therefore a genus consists of the different

[1] The original meaning of *macrocarpa* is "large-fruited," or "large-seeded."

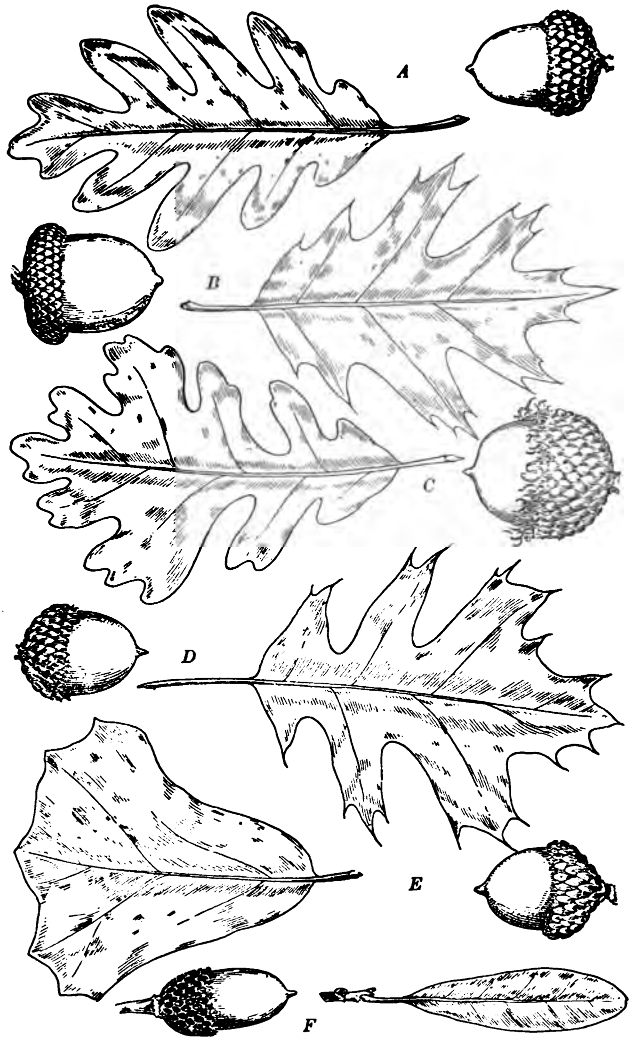


FIG. 164. A group of leaves and acorns illustrating some of the differences between six species of oak (*Quercus*)

***A*, the white oak (*Q. alba*); *B*, the red oak (*Q. rubra*); *C*, the bur oak (*Q. macrocarpa*); *D*, the black oak (*Q. velutina*); *E*, the blackjack oak (*Q. marylandica*); *F*, the live oak (*Q. virginiana*). The acorns are about three fourths natural size and the leaves less than one half natural size. Modified from R. B. Hough**

species that belong to it. A careful study of figure 164 will give some notion of the relative resemblances of two structures in these six species of *Quercus*. In speaking of plants it is customary to use both genus and species name (that is, the binomial system of names), as *Quercus alba;* or, more often, we use the common name, as *white oak*. Elementary botany formerly concerned itself chiefly with attempts to learn the genus and species names and the proper classification of seed plants. We are now concerned more with how plants live than with what their botanical names are.

183. The leading groups of plants. Those genera (plural of *genus*) which resemble one another are grouped together into a *family;* families with sufficiently close resemblances are grouped into an *order;* orders are grouped into *classes;* and classes into *great groups*. A study of the following divisions of the plant kingdom will enable you to see the relations that these divisions bear to one another, and the relations of genus and species names to the whole plan of classification.

Plant kingdom
- Great groups
  - Classes
    - (Sometimes sub-classes)
      - Orders
        - Families
          - Genera
            - Species
              - (Sometimes varieties)

The four great groups of plants are

Spermatophytes, the seed plants in which are:
- *Angiosperms*, or plants with inclosed seeds;
- *Gymnosperms*, or plants with exposed seeds.

Pteridophytes, the fern plants, including the common ferns and other fern-like plants that are not so common.

Bryophytes, including liverworts and mosses.

Thallophytes, including the lowest and simplest plants — the fission plants, the algæ, and the fungi.

Some of these groups will be very briefly considered in the chapters immediately following.

ASA GRAY

Asa Gray, foremost American botanist of the nineteenth century (b. 1810; d. 1888), was trained to be a physician, but relinquished medicine for botany. He taught during the school year, made collecting trips in summer or worked in European botanical centers, and built up the famous Gray Herbarium of Harvard University. As professor of botany at Harvard from 1842, he taught many of the older botanists of the present generation. In 1836 he began a series of elementary textbooks, which were widely used for more than fifty years. His many botanical publications are chiefly systematic. A great teacher, a close friend of his students, a constant worker and author of admirably written scientific and popular articles, he is the most important figure among the founders of botany in America

184. Divisions upon bases other than structure. As already suggested (section 181), plants may be grouped upon the basis of their place of living or mode of life. Also, sub-divisions of the study of plants may be designated by the particular point of view that is kept in mind in pursuing the study. The study of the classification of plants into their proper groups and the determination of their proper generic and specific names is called *taxonomy*, or *systematic botany*. When emphasis is placed upon a comparative study of plant organs and their relationships, the study is known as *plant morphology*. Special study of the cell is *cytology*. Plant activities or work and their relations to the immediate surroundings of the plant are included in *physiology*, while the relationships of plants to one another and to the environment in general is *ecology*. One phase of ecology deals with the distribution of plants over the earth and is known as *ecological plant geography*. The study of plant diseases is known as *phytopathology*, or *plant pathology*. A study of the bacteria constitutes *bacteriology*. A consideration of the useful or harmful aspects of plants is included under the general term *economic botany*, and under this head there are such sub-divisions as *agricultural botany* and *horticultural botany*. These are but the leading aspects under which plants may be studied.

It is evident that these divisions have no sharply marked lines between them, and that they are not all made upon the same basis. For example, we might study the bacteria with reference to their structure, which would be morphology; or in their relation to disease, which would be pathology; or in their relation to farm and garden crops, which would be economic botany.

185. Names necessary as labels. In the following chapters we shall study a few representatives of the leading great groups of plants. It is necessary to have specific names for the plants that are used as illustrations of these groups, for sometimes the plants used do not have common names, and sometimes the common names, when used, are applied to two

or more different species of plants. We must, however, keep in mind the fact that what we really want to find out is not primarily the names of plants, but what plants are, how and where the different groups live, how they reproduce themselves, and how their habits of living are related to the life of other living things. We must have definite names for plants and for their parts in order to be clear when we speak of them, just as we need names for different people in order that we may designate them in a definite way, although we are more interested in what they are and what they do than in their names.

CHAPTER XIV

THE BACTERIA

186. What are the bacteria? When a dish of water in which cut flowers have been kept for several days is carefully examined, a thin film, or scum, may often be found on the surface of the water. This surface film usually consists of many millions of bacteria. The bacteria have thrived upon the plant substances which were dissolved in the water. The bacteria also produce the unpleasant odors that often arise from such a dish of cut flowers. If but a few bacteria had gathered at the water's surface, they could not be seen except by the use of very great magnification, but when such large numbers accumulate in one place, they may easily be seen, just as it is easier to see a pile of sand than it is to see a few grains of sand.

The bacteria are extremely simple one-celled plants. The fact that they are plants was not generally recognized until within the past few decades. Although this group of plants is still imperfectly known, much has been learned of their very great hygienic importance. It has been popularly supposed that all or nearly all of the bacteria are causes of disease, although it is now believed by scientists that very few of them are disease-producing. On the other hand, there are many kinds of bacteria that live in such ways as greatly to aid in important processes upon which men depend.

187. The size and structure of the bacteria. The bacteria are so small, and there are so many kinds of them,[1] that it is not easy to give a clear answer to the question as to what they are. Indeed, they are so small that the figures given for

[1] It has been estimated by Migula, a good authority, that there are at least 1272 distinct species of bacteria.

their size are almost meaningless. When we say that average rod-shaped bacteria are about $\frac{1}{10000}$ inch ($\frac{1}{400}$ mm.) long, and $\frac{1}{25000}$ inch ($\frac{1}{1000}$ mm.) in thickness, we are describing dimensions so small that we cannot appreciate them. It must also be kept in mind that many kinds of bacteria are smaller than the dimensions given above. These figures mean more when we calculate the number of average bacteria that might be contained in a vessel measuring a cubic inch, or when we measure the thickness of a finger nail and estimate how many bacteria, piled one upon another, would be required to make a column as high as the finger nail is thick. Such estimates will make it quite clear that bacteria are small enough to be everywhere and yet escape our attention. Bacteria are of three different forms. Most of them are rod-shaped, or of the *bacillus* form, some are *spherical*, and still others are *spiral* in form (fig. 165). The rod bacteria vary in length and in diameter. Similarly, spherical bacteria vary in size, and some spiral forms may consist of less than one complete spiral, others of a dozen or more spirals.

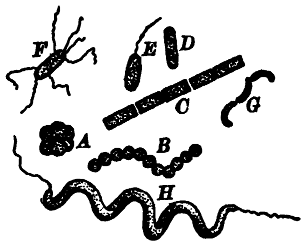


FIG. 165. A group of bacteria illustrating type forms

A, spherical bacteria gathered into a colony, and *B*, spherical bacteria arranged in a chain; *C*, *D*, *E*, and *F*, rod, or bacillus, bacteria, *E* and *F* having cilia; *G* and *H*, spiral bacteria, the former less than one complete spiral, and the latter several spirals. Rearranged after Jordan

Little is known about the structure of these minute plants. The definitely organized cell wall contains a small amount of protoplasm, which sometimes forms extruding cilia (fig. 165). By means of these cilia some kinds of bacteria are able to swim, and some of them move with a speed (over two thousand times their own length in one hour) which is remarkably rapid in proportion to their small size. Definite nuclei have not been seen in bacteria, but it may be that certain granular fragments represent the nucleus. We are more interested, however, in how bacteria live than in their structure.

188. How bacteria secure their food. Since they are so simple in structure, and since they live in direct contact with their food supply, the bacteria absorb their nourishment directly through their cell walls. Different kinds of bacteria may live upon different kinds of organic matter, but almost every kind of organic matter may serve to nourish some kind of bacteria. Certain kinds of bacteria can thrive only in absence of free oxygen, and a few others can construct food somewhat as green plants do. It must also be noted that bacteria, like other living things, produce and excrete substances which, if retained, would be injurious to them. If excreted and accumulated about the bacteria in great quantity, these substances would soon kill them. If a jar of beef broth is carefully sealed after any ordinary bacteria have been introduced into it, there will at first be a rapid increase in their number, and the liquid will become clouded with the organisms and their products. But the excretions soon accumulate to such an extent that the bacteria can no longer grow. They become dormant or may die and settle to the bottom of the jar or collect in a jelly-like mass at the surface.

189. How bacteria reproduce themselves. When in favorable nutrient material, bacterial cells divide frequently. A plant thus forms two new ones, each of which may soon (in from twenty minutes to half an hour) divide again. This is the simplest possible method of reproduction, consisting merely of the dividing, or fission, of a single-celled plant. The possibilities of this rate of reproduction are enormous. If all conditions were to remain entirely favorable for reproduction, a bacterium which divides but once an hour would in two days produce offspring numbering 281,500,000,000, and "in three days the progeny of a single cell would balance 148,356 hundred-weight."[1] Of course it is well known that ordinarily this rate of reproduction cannot be realized, because growth conditions do not remain favorable. The food supply

[1] Jordan, E. O., General Bacteriology, p. 62. W. B. Saunders Company, 1911.

is soon exhausted, and the excretions from the bacteria themselves interfere with their growth and reproduction. But in situations where bacteria can grow they really do reproduce themselves and increase their number with astonishing rapidity (fig. 166). The possibilities of production and growth of large

FIG. 166. Gelatin culture of bacteria

The sterilized gelatin in the dish was exposed in the hallway of a schoolroom for five minutes, and then kept covered for five days, during which time the different colonies of bacteria grew. Each colony grew from one, or possibly, in some cases, from a few individual bacteria, and the number of bacteria that have grown in each colony is so large that the colony is easily seen

numbers are evident when we remember that many millions of bacteria could live for a considerable time in a cubic inch of milk or beef broth.

In a few kinds of bacteria the interior of the cell sometimes becomes rounded and inclosed by a relatively heavy wall. This heavy-walled body may remain inactive for a long period,

and, upon the return of favorable conditions, may grow and produce the kind of cell which formed it. Such specially produced reproductive cells are called *spores*. They often enable the bacteria and other plants to live through periods of unfavorable conditions — as drought, lack of proper air, absence of suitable food, and unfavorable temperature. Some kinds can withstand freezing or boiling temperatures. It is much more difficult to destroy the spores of bacteria than the vegetative, or growing, cells. There are very few spore-forming bacteria among those that produce diseases of men. This is fortunate, since the problem of combating disease would be much more complex if all the harmful bacteria should be able to form these resistant spores. A disease known as anthrax offers a good illustration of the way in which spore formation may increase the distribution of disease. Anthrax is a very destructive disease, as is shown by the fact that, prior to the use of the treatment devised by Louis Pasteur, France in single years has lost as much as $20,000,000 worth of cattle and sheep. The disease also affects men and may cause their death, as it does that of cattle, sheep, and other animals, in from a few hours to a few days after infection. The spores of anthrax form only when the bacteria are exposed to the air. When an animal dies of anthrax, if its body decays while exposed to the air, millions of anthrax spores are formed. These spores can lie in the field for very long periods, probably several seasons, and withstand the variations in temperature, moisture, and light. When they are introduced into the alimentary tract of an animal, they soon reach the circulatory system, where they grow with surprising rapidity and may soon cause the death of the newly infected animal. The desirability of the complete destruction of bodies of animals that have died of anthrax is evident.

190. Bacterial decay and its significance. The bacteria and certain other dependent organisms (as molds, yeasts, and many animals), while living upon the bodies or the products of plants and animals, use parts of them as food. The processes

of securing this nutriment result in partial or complete breaking down of the food substance. This is known as decay. While a body is undergoing decay, usually several kinds of bacteria and other organisms live in turn upon it. In complete decay all of the nutrient organism is used as food, or passes into the air as gases, or is dissolved in water and carried into the earth or into streams. The materials that result from decay are not only directly the remnants of the original plant or animal body, but may also contain excretions from decay-producing organisms. Furthermore, many of these organisms of decay have themselves died and decayed.

Processes of decay are of great biological importance. It is necessary to have the dead bodies and the waste products of living bodies reduced to a form that makes their removal possible. The materials that are broken down are thus made usable for the future growth of plants and animals. Without decay all usable food material would eventually be rendered unavailable for the future growth of plants and animals, so that life on the earth would cease. The earth's supply of food materials would be locked up in organized plant and animal bodies.

It has long been known that the introduction of decayed and decaying organic matter into soils enables them to sustain a more luxuriant vegetation. Undecayed organic matter is not available for agricultural or horticultural plants. Such material must await more complete disorganization before it can be useful. It is desirable to regulate this decomposition so that the largest possible amount of its products may be retained in the soil. This is one of the problems of scientific agriculture (see Chapter XIX). For example, if stable manure in large masses is allowed to heat under the rapid destructive action of the bacteria and other living things which flourish in it, much valuable ammonia is given off into the atmosphere and lost. Slower decay, especially if underground, wastes but little ammonia.

191. Bacteria and soils. In an earlier part of this book we learned that nitrogen compounds are necessary for the construction of part of the food which plants must have. In the

preceding section the relation of decay to soils was suggested. Although the relation of plants and soils is more fully discussed in a later chapter, it is advisable at this point to discuss briefly the relation of bacteria to soils. Their methods of living bear peculiar relations to the nitrogen supply of the soil.

There are at least four groups of soil bacteria which are of interest in this connection. First, there are saprophytic forms which in their processes of nutrition make a compound of nitrogen and hydrogen which is known as ammonia. This bacterial action is known as ammonification, which means "ammonia-making," and the bacteria which are responsible for the action are called the ammonification bacteria. Second, there are the so-called nitrite bacteria, which in their process of nutrition change ammonia into other compounds in which there is one part of nitrogen to every two of oxygen. Such compounds are called nitrites. Third, there are the nitrate bacteria, which change nitrites into compounds in which there is one part of nitrogen to every three of oxygen. Such compounds are known as nitrates. These last two processes are spoken of as nitrification. Fourth, there is a still different and most important group of bacteria which enter the roots of certain kinds of plants, as clover, soy beans, peas, and alfalfa. When some of these bacteria have entered the roots, they become surrounded

FIG. 167. Bacterial tubercles on the roots of the cowpea [1]

A, leaves of the cowpea; *B*, part of the root system of the cowpea, with numerous tubercles, the tubercles being induced by bacteria which gather nitrogen from the air of the soil. One third natural size

[1] From "Nitrogen Bacteria and Legumes," *Bulletin 94*, S.C. Exp. Sta.

by tissue, so that they form nodules, or tubercles (figs. 167 and 168). Within these tubercles the bacteria are able to take the uncombined nitrogen from the air of the soil and combine it with other substances in such a way as to form nitrates. The tubercle bacteria are known as the nitrogen-fixing bacteria, since they take free nitrogen from the air and combine it with other things so as to make plant foods.

Since the ordinary grain-producing plants must have nitrogen in order to grow, and since they can use it only in the nitrate form, the significance of these tubercle bacteria to agricultural plants is evident. Agriculturists have known for a long time that, after growing a crop of clover or peas, the soil is in better condition for growing other crops, but the way in which this is brought about, and the relation of bacteria to the process, are matters of recent knowledge. The clover, alfalfa, peas, and beans grow better when the tubercle bacteria are present (fig. 169), and the added nitrates left by decay of the tubercles and the plants upon which they grew enrich the soil for subsequent crops.

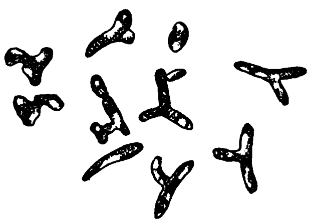


FIG. 168. Bacteria, or bacteroids (meaning "like bacteria") which grew in the root tubercles[1]

There are many other kinds of soil bacteria, one kind living in such a way as to denitrify nitrate compounds, thus working in a manner opposite to some of the above groups.

192. Bacteria and the destruction of foods. From what has been said in preceding sections it is evident that all our fruits, vegetables, meats, etc. are at times in danger of destruction by bacteria or other organisms. How to prevent this destruction has been one of the important problems since civilization began. Surplus production of food is useless unless some of it may be kept for future needs.

[1] From Lipman, Bacteria in Relation to Country Life. The Macmillan Company.

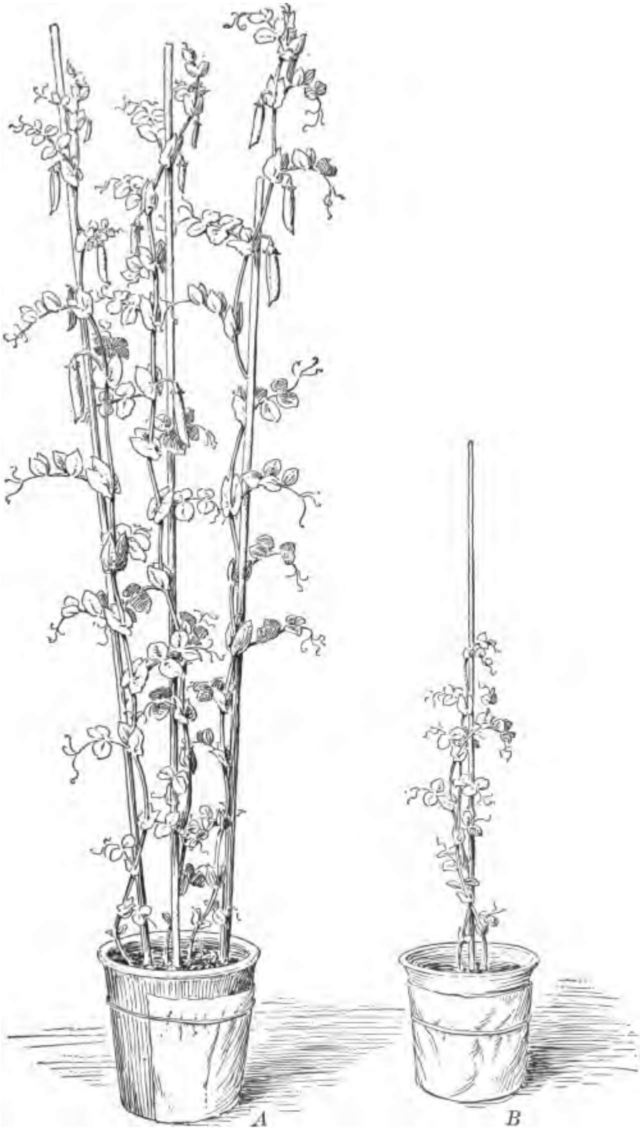


Fig. 169. Cultures of peas of the same age and from the same kind of seed, one (A) with root-tubercle bacteria and one (B) without. After Frank

In the preservation of fruits much progress has been made by improvements in methods of gathering them. Most fruits have a natural covering, which, if unbroken or unbruised and kept clean, will for a long time prevent the entrance of organisms of decay. If two sets of ripe apples are gathered — one carelessly, so that bruising and scratching of the surface occurs, the other with sufficient care to avoid these injuries — and both are kept under similar conditions, an interesting demonstration will be made of the desirability of proper care in handling fruit.

193. Refrigeration and drying. Long before it was known how decay is produced, it was known that low temperature and drying would prevent decay. Refrigeration has now become the chief method of preventing decay, since bacteria do not thrive at or below the freezing point. There is doubt whether bacteria grow at all when at freezing temperature, but this point is not definitely settled. Foods are kept for years by cold or by drying, and are thus shipped all over the world. Fruits, meats, and grains, when completely dried (a natural process of preservation), may be kept for years, since destructive bacteria cannot thrive upon thoroughly dry food. Preservation in salt and sugar or their strong solutions serves the same purpose as drying, since salt and sugar have such avidity for water that destructive organisms have their protoplasmic water extracted and therefore cannot grow. Fish, beef, pork, and other meats may be preserved by smoking with wood smoke. The creosote that is carried into the meat by this process helps to prevent the growth of destructive organisms. This method of preservation, though thoroughly wholesome, requires long exposure to the smoke. It is not so extensively used for beef and pork as formerly, though large quantities of fish are still preserved in this manner.

194. Sterilization and canning. High temperature may also prevent the growth of bacteria, and by its use sterilization and canning have recently offered very great opportunities for food preservation and shipment. By means of heat properly applied all bacteria and other organisms of decay may be

killed. If such completely sterilized food is hermetically sealed in vessels that have been similarly sterilized, it will not decay. It is difficult, but entirely possible, to thoroughly sterilize both food and sealing appliances so that absolutely no organisms will grow.[1] Other methods of preservation by the introduction of chemicals (antiseptics) that prevent the growth of bacteria are sometimes used. These chemical preventives are poisons. If eaten in very small quantities, injurious results may not be immediately noticeable, but the use of these preventives is attended by constant danger. Milk, meats, and confections that are so preserved should always be avoided.[2]

195. Preservation of milk and water supply. The relation of bacteria to milk and water supply is a subject of the greatest importance. A rather large number of harmless bacteria may often be found in reasonably pure milk and water, but careless handling of bottles and cans, or the use of tuberculous cows, may result in widespread disease. If milking is done through absorbent cotton or through several layers of cheesecloth, used as a cover for the milk pail, most of the impurities are caught in the strainers. Milk pails and shipping cans and milk bottles should always be sterilized before they are used. Milkmen who were otherwise fairly careful in their work have been known to rinse their pails and cans in polluted wells or streams. Bacteria which produce various kinds of disease have thus been distributed. Either milk or water may be sterilized by boiling, and may be kept sterile if placed in sterile vessels. Both, however, are better if they can be kept in a pure condition without sterilization. An efficient method of preserving milk is by pasteurization,[3] in which the

[1] Abel, Mrs. Mary Hinman, "Care of Food in the Home," *Farmers' Bulletin 375*, U.S. Dept. Agr., 1909.

[2] Sometimes in canned goods, stale meats, and other foods, poisonous substances known as ptomaines are formed. It is supposed that they are produced as secretions from bacteria, as results of chemical change or decay of such foods as meats and fruits, or even from the disorganization of some of the bacteria.

[3] "Directions for the Home Pasteurization of Milk," *Circular 152*, Bureau of Animal Industry, U.S. Dept. Agr., 1912.

vessels containing the milk are placed in water and brought to a temperature of 150° to 155° F., and then cooled and kept cool until used. This method kills most of the bacteria in milk and makes less change otherwise than does boiling.[1]

Bacteria are important in connection with many other industries. The formation of acetic acid (the acid of vinegar) is due to the growth of several kinds of bacteria. Part or all of the processes of curing tobacco, tanning leather, preparing plant fibers (as flax and hemp), and making butter and cheese depend upon the growth processes of different kinds of bacteria.

196. Bacterial diseases of plants and animals. Although many bacteria grow constantly upon and within other plants and animals, these are usually not disease-producing bacteria. Sometimes, however, malconditions in the host plant or animal are produced by bacteria, and disease and death of the host may result.[2]

Brief reference to a few kinds of bacterial disease will afford illustrations of some of the effects produced upon plants and animals (fig. 170). In the case of black rot of cabbage the bacteria enter the cabbage leaf through the leaf pores. Once within the leaf, they grow rapidly, and brown or black spots appear on the leaf as outward evidence of the inward ravages of the parasites. These leaves may become shriveled. The disease may spread throughout the plant and result in destruction of the entire head of cabbage.

"Pear blight" is a disease which often seriously affects the leaves, young twigs, and fruit of the pear and apple. The bacteria cannot live under long exposure to direct sunlight

[1] "Care of Milk on the Farm," *Farmers' Bulletin 63*, U.S. Dept. Agr., 1906.
"Bacteria in Milk," *Farmers' Bulletin 348*, U.S. Dept. Agr., 1909.
"Sources of Bacteria in Milk," *Bulletin 51*, Storrs Agr. Exp. Sta., Storrs, Conn., 1908.
"Milk and its Products as Carriers of Tuberculosis Infection," *Bulletin 143*, Bureau of Animal Industry, U.S. Dept. Agr., 1909.

[2] A few diseases are caused by small animal parasites, but since these are not bacterial diseases, they are not included in this discussion.

or to drying, but can endure low temperatures. During the winter they live in the diseased twigs. In the early growing season the leaves and young growth of the twigs become blackened and soon wilt as a result of the internal growth of the parasite. The bacteria secure nourishment from the cells of the host. They may partially or wholly stop the cellular passages of the host, and are possibly injurious in other ways.

FIG. 170. A crown gall produced by bacteria (*Bacillus tumifaciens*) on young apple tree[1]

A, the tissue of the apple plant which grew around the infected area, thus producing the knotted growth known as the gall. One third natural size

The question of how these bacteria are distributed to new hosts is important. Even if they should be carried through the air, and should withstand the consequent drying and sunshine, and should fall upon the surface of twigs, leaves, or fruit of the proper host, it is said that they could not make their way into the tissue. It is believed that the common method of infection is by means of biting or stinging insects or of nectar-hunting insects that visit the flowers and fruit. When a few bacteria are inserted into a new twig, leaf, or floral structure, the infection may spread several inches, and soon the blighting begins. When one flower is infected, insects may carry the bacteria to almost every flower on the tree or on other trees in the vicinity. Moreover, when the disease has developed far enough for the characteristic gummy exudations to appear, insects that bite into them may become loaded with the bacteria and may insert some of them into a new host. In pruning

[1] From "Field Studies of the Crown Gall and the Hairy Root of the Apple Tree," *Bulletin 186*, Bureau of Plant Industry, U.S. Dept. Agr., 1910.

both diseased and healthy twigs, the knife may be the means of transferring bacteria. If all infected parts are removed and burned, and if the knife used in pruning diseased twigs is sterilized before being used in pruning healthy plants, the continued spread of the disease is made unlikely.

197. Diseases of man. In the section on nutrition of the bacteria (sect. 188) attention was directed to the fact that excretions are regularly produced by them. In case of disease-producing forms, some of these excretions are injurious or poisonous, and are known as *toxins*. In susceptible plants or animals toxins may produce disease. Each kind of disease-producing bacterium forms its own peculiar toxin or toxins, which in time may produce a particular kind of disease. Substances that neutralize toxins are known as *antitoxins*. In the body of the diseased organism antitoxins are produced which, when formed in sufficient quantities, counteract the influence of the toxins. When one has had an attack of smallpox or diphtheria and has produced sufficient antitoxin to enable him to overcome it, he is usually not susceptible to another attack of the same disease. He is *immune*. There are other diseases (such as mumps, measles, and scarlet fever) against which most people may acquire immunity by once surviving an attack. This immunity is usually lifelong, though exceptions are known. In the case of other diseases (such as typhoid and influenza), one may become susceptible to another attack. Some people are naturally immune to certain diseases.

Smallpox vaccination[1] consists in infecting human beings with organisms that have been grown in such unfavorable ways that their ability to produce disease is greatly reduced. Consequently the result of vaccination is to cause a very mild attack, which produces immunity against fully virulent smallpox. This lasts for a period of years (usually given as seven years), though the protective effect gradually diminishes.

[1] The specific organisms which produce smallpox have not been fully identified. It is thought by some that smallpox is caused by an animal organism somewhat like the malarial parasite, and not by bacteria.

198. Preparation of antitoxin. It has been found possible to secure from horses and mules an antitoxin that will counteract diphtheria toxins in the human body. These animals are naturally immune to diphtheria, but by injecting into their bodies toxins produced in beef broth by diphtheria bacteria, this natural immunity is greatly increased. First into the animal's body there is injected a small amount of toxin. This process is repeated, with an increasing amount, at intervals of a week or a little less, for a period of two or three months. The animal finally withstands, with no ill consequences, an amount of toxin that would have proved fatal if used at first. At this time some of the blood is drawn off and allowed to clot, and the antitoxic serum is sterilized. This antitoxic serum is usually concentrated, in order to make it possible to inject the desired strength of antitoxin without an unnecessarily large amount of liquid. After its relative strength is determined, it is sealed in small bottles and is ready for distribution. A human being who has diphtheria may then be given the proper amount of antitoxin. If it is properly given, and given early enough, the attack is defeated.[1]

AVERAGE ANNUAL DEATH RATE FROM DIPHTHERIA PER 10,000 POPULATION[2]

	Before use of antitoxin (1885-1894)	Antitoxin period (1895-1904)
Paris	6.41	1.49
Berlin	9.93	2.95
Vienna	8.14	2.95
London	4.85	3.88
New York	15.19	6.62
Boston	11.76	6.34
Baltimore	7.34	4.99
Chicago[3]	14.29	5.13

[1] A few inexcusable cases have occurred where impure antitoxin was used.

[2] Jordan, E. O., General Bacteriology, 1911.

[3] The use of antitoxin was begun in 1895-1896; the death rate dropped from 12.01 in 1895 to 7.62 in 1896.

199. Benefits from use of diphtheria antitoxin. Great benefits have come to the human race through the discovery of diphtheria antitoxin. It was generally introduced in 1894. A study of the table on page 213, containing data for ten years before and ten years after the introduction of this remedy, will give an idea of the value of this scientific discovery.

200. Tuberculosis: the great white plague. The disease commonly known as tuberculosis is so generally distributed and so destructive that it has been called "the great white plague." Its universal importance demands that a separate section be given to a brief statement concerning it. It is the most destructive disease that affects the human race, and in the United States it causes about one ninth of all deaths.

The lungs are the organs most frequently attacked, though the bones and joints, the intestines, the throat, the skin, and other organs are often infected. The growth of tubercle bacilli in the body is usually very slow, and months or years may pass before conspicuous consequences follow infection. Furthermore, the bacilli may live upon a handkerchief, in the floor of a house, in a public building, in public-transportation vehicles, or in the dirt of the street, for a very long time, and then grow when they are introduced into the human body. Some of the lower animals (cattle, hogs, and poultry) are subject to tuberculosis and may infect human beings.

Infection is usually through the organs of breathing, though the germs may be introduced into the digestive system in milk and other food. Persons who have tuberculosis may "expectorate from 500,000,000 to 3,000,000,000 tubercle bacilli in twenty-four hours."[1] Also, such persons, while coughing, may inject into the air very small droplets which contain many bacteria, and these may float in the air for a short time. Since the dried or partially dried tubercle bacilli may be transported by the air, it is evident that every precaution should be taken to keep the air from becoming contaminated. Furthermore, it is known that when tubercle bacilli are moist,

[1] Jordan, E. O., General Bacteriology, 1911.

the direct light of the sun has a destructive effect upon them, and that fresh air is likely to contain fewer tubercle bacilli than the close air of rooms in which many people have been. Plenty of fresh air, sunshine, and wholesome food are most important factors in preventing attacks of tuberculosis, and these, together with good general vitality of the body, are the best guaranty against this disease. On the other hand, poor food, bad air, dark rooms, and low vitality render the body a favorable growing place for these germs, when once they are introduced. These predisposing factors are of tremendous importance in relation to tuberculosis. The nature of the occupations and habits of men have much to do with predisposing and exposing them to this disease. In 1898 an Englishman named Newsholme showed by records that for each 100 agriculturists who died from tuberculosis and other respiratory diseases there were 453 potters and earthenware workers, 407 cutters, 373 plumbers, and 335 glassmakers who died from these same diseases.

201. Prevention of disease. Bacteria are distributed into almost every nook and corner of the earth — in soil, air, water, and dust, and upon and within the bodies of plants and animals. Disease-producing bacteria are common, though far less abundantly distributed than forms which do not cause disease. It must be kept clearly in mind that if all disease-producing bacteria from patients who have disease were immediately killed, there would soon be no danger of distribution of disease by any of the ordinary agencies. A good deal is known about the methods of distribution and infection of the most dangerous disease-producing forms, though our knowledge is by no means complete. Polluted water and milk have often been the means of wholesale distribution of typhoid germs (fig. 171). There are numerous records of cases in which the typhoid pollution of rivers has been directly followed by outbreaks of typhoid in cities that get their water from these rivers. There are also instances where typhoid-polluted milk has left a trail of typhoid wherever it was used.

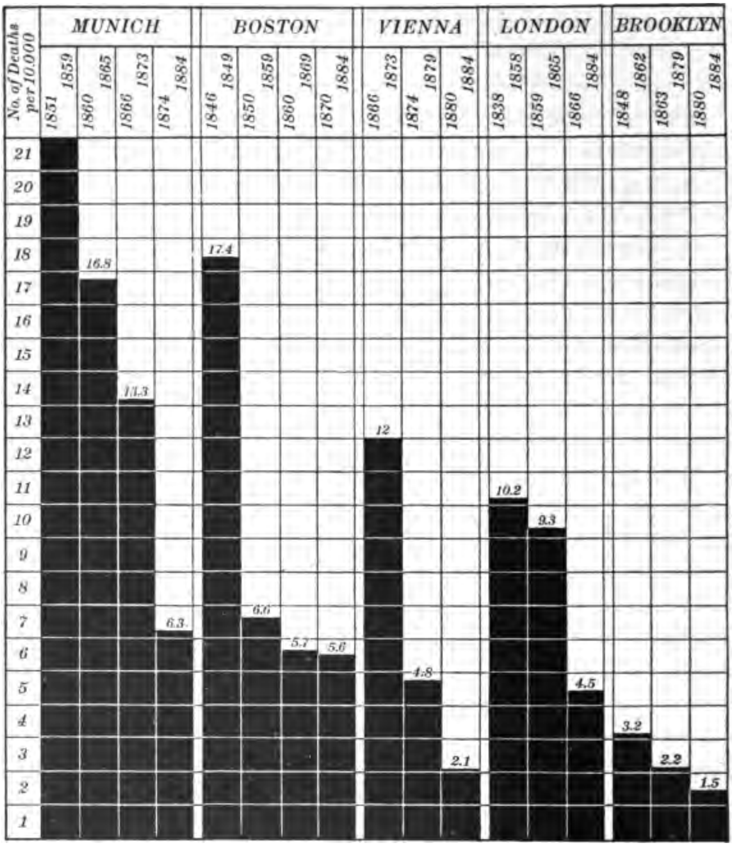


FIG. 171. A chart illustrating the number of deaths from typhoid fever before, during, and after the introduction of improved systems of sewage disposal and water supply

Five prominent cities of the world are selected. The figures indicate the number of deaths for each 10,000 inhabitants. Rearranged from a chart in Abbott's "Hygiene of Transmissible Diseases"

The house fly is a dangerous agent of distribution of typhoid and probably of other disease bacteria. The atmosphere is an efficient carrier of the bacteria of tuberculosis. Every possible effort should be made to remove the breeding places of flies

(refuse from stables, exposed and decaying garbage, etc.) and to keep flies out of public and private dwelling places; to insure a pure and well-kept supply of milk and water;[1] to keep vegetables and other foods that are sold in public places free from dust and flies and promiscuous handling; to disinfect all known or suspected disease-bearing materials of all kinds;[2] to have abundance of fresh air; to have all the sunshine possible, since sunshine is destructive to many disease germs.

202. Importance of high standards. The maintenance of a high standard of vigor is evidently important as a means of preventing bacterial disease. Many people have had disease-producing bacteria introduced into their bodies without any serious consequences — indeed, without even being conscious of danger. They were in such vigorous condition that the initial growth of bacteria was prevented. An instructive experiment relative to this point was performed by Pasteur. Ordinary domesticated fowls are not readily susceptible to anthrax; Pasteur found, however, that if he kept the fowls at lower temperatures than was normal for them, they were very susceptible to anthrax, and that under such circumstances it proved deadly to them. This is a common principle of hygiene. When, through excessive fatigue, loss of proper sleep or nourishment, or any other cause, bodily vigor is greatly reduced, susceptibility to disease is increased.

Modern bacteriology has offered the human race the means of escape from many diseases. Ignorance, lack of care, and financial greed are often the only excuses that can be offered when certain diseases occur. If only those who are responsible

[1] In Germany it is unlawful for filtered water to contain more than 100 bacteria per cubic centimeter, and it should always contain less. Boston has a legal standard which requires that market milk shall not contain more than 500,000 bacteria per cubic centimeter, and Rochester, New York, and Milwaukee, Wisconsin, have legal standards of 250,000 per cubic centimeter. Certified milk should not contain over 10,000 bacteria per cubic centimeter. There is milk in which the number runs from one million to several millions.

[2] In "Bacteria, Yeasts, and Molds in the Home," by H. W. Conn (Ginn and Company), there is an excellent popular discussion of the nature of bacteria and the effects of their growth.

for them were attacked by these preventable diseases, the matter would not be so serious, for in that case disease and the resulting deaths would tend to eliminate those who do not act upon the knowledge of sanitation which we now possess; but many innocent people suffer because others do not take proper precautions against the spread of diseases over which they might have control. As one means of protecting the public many states have laws preventing the use of public drinking cups. Attempts are made to have school children drink from running water, so as to make sure that all contaminated water flows away. We need many more regulations of the same kind in order to guarantee a reasonable security against the needless spread of disease.

PROBLEMS

1. How can you show that the process of decay is of advantage to living things? Would decay take place without the action of dependent organisms?

2. What are the relative advantages and disadvantages of preventing the decay of food by refrigeration and by the use of chemicals? Why are chemicals sometimes used where other means of preservation might be adopted?

3. What are the surest methods of preventing the spread of bacterial diseases of plants, such as pear blight and the black rot of cabbage?

4. Would the fight against typhoid fever be won more quickly by destroying all flies that carry typhoid or by destroying all infecting material from persons who have typhoid?

5. In your school and community what are the chief needs for a better understanding of the nature of bacterial diseases?

6. What are your local regulations in regard to quarantining persons ill with infectious diseases? in regard to preventing the introduction of diseased fruit trees? of diseased animals?

7. What bulletins has your state agricultural experiment station or your state board of health published dealing with the relation of bacteria to human disease, diseases of farm animals, dairying, household industries, or agriculture?

LOUIS PASTEUR

Louis Pasteur, the world's most noted bacteriologist (b. Dôle, France, 1822; d. Paris, 1895), in studying fermentation, was the first to develop accurate methods for securing pure cultures. When the nature of bacterial disease was unknown, he discovered the causes of two destructive diseases of silkworms (from which France had lost sometimes as much as $20,000,000 in one year), proved that the diseases are infectious, and showed how to avoid them. Though partially paralyzed (1868), he devised means of treatment for hydrophobia, taught men the possibility of freedom from disease, and laid the foundation for modern bacteriology and public hygiene. In recognition of his services to the world he was given a gold medal inscribed "To Pasteur, France and Humanity Grateful"

CHAPTER XV

THE ALGÆ

203. Introductory. Since they usually grow in water, the algæ are sometimes spoken of as pond scums, water mosses, sea mosses, and seaweeds. Both fresh and salt waters serve as growing places for the algæ, and they often appear in such abundance that great mats of plants are formed upon or below the surface of the water. There are many different kinds of algæ, and they are divided into four groups, the chief distinguishing character being their color. The most common algæ have a distinctly green color and are known as the *green algæ*. Others, also quite common, have their chlorophyll mixed with a blue coloring matter, so that they are bluish green, and these are known as the *blue-green algæ*. These two groups of algæ are found chiefly in fresh waters. There are two other groups found usually in salt waters. In one of these, the *brown algæ*, there is a brown coloring matter mixed with the green, and in the other, the *red algæ*, the green is obscured by red, which often becomes most striking in its hues.

204. The blue-green algæ.[1] Masses of these blue-green plants may often be seen in pools of stagnant water or upon wet soil. Sometimes they appear as slimy coatings upon sticks, stones, and poorly cleaned watering troughs for farm animals, and they may also appear as free-floating, dirty mats or balls. The blue-green algæ are very widely distributed, and there are many kinds, of which *Nostoc* and *Oscillatoria* are quite common and may serve to illustrate the group.

[1] In structural details blue-green algæ are probably more closely related to bacteria than to other algæ, but because of their general appearance and habits of living they are mentioned briefly with the algæ.

The bluish-green balls (fig. 172, *A*) of *Nostoc* plants are found upon damp soil or floating upon stagnant water. Under magnification[1] the *Nostoc* ball is seen to be composed of granular jelly, interwoven by many chains of cells, each of which is a *Nostoc* plant (fig. 172, *B*). These chains often divide into two or more shorter chains, breaking where there are large, dead cells (*heterocysts*), and each chain proceeds to live as a new plant. *Nostoc* may absorb the materials needed for photosynthesis directly through the cell walls, or it may perhaps absorb organized foods as do the bacteria, since much food of this kind is present in the water in which the plants live. In times of drought the jelly balls dry slowly and may become dry enough to crumble easily, but when a favorable amount of moisture returns, the plants within the ball may proceed to grow.

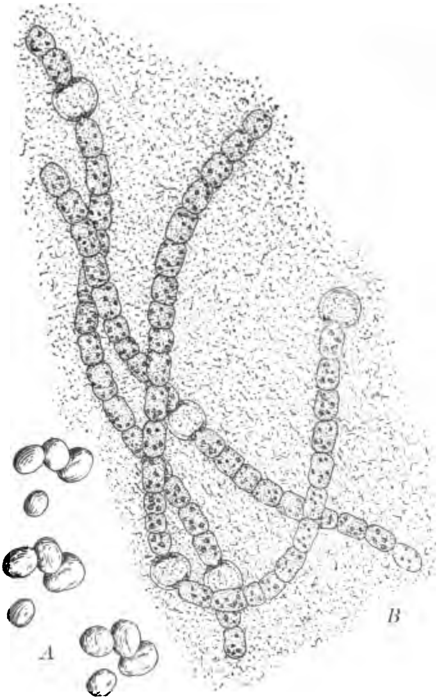


FIG. 172. *Nostoc*

At the left (*A*) are several of the *Nostoc* balls, which appear as glistening, rounded masses (natural size). At the right (*B*), inclosed in gelatinous material, are a few chains of *Nostoc* plants which have been taken from one of the balls and greatly magnified. In the chains several of the enlarged heterocysts may be seen

[1] When beginning the study of the algæ it is often better to use a good specimen under a demonstration microscope than to attempt individual microscopic work. If preceded by preliminary demonstration work the following individual studies will be more intelligible and successful.

Oscillatoria grows in the same kind of region as *Nostoc*, but is more abundant. It appears as floating mats or as slimy coatings upon objects in the water. Frequently sticks and stones on the bottom are covered with a beautiful velvety layer consisting of multitudes of these simple plants. The individual plants are thread-like (fig. 173) and often have a swinging, gliding, or oscillating movement, from which the name of the plant is derived. In stagnant or foul water *Oscillatoria* plants grow vigorously, being able to thrive throughout a wide range of temperature. The cells of the plant divide, thus lengthening the plant. Later the threads break into two or more new threads, each of which continues to grow as an independent plant. The cells of one plant are inclosed in jelly-like sheaths, but there is no jelly mass which holds many plants together, as in *Nostoc*.

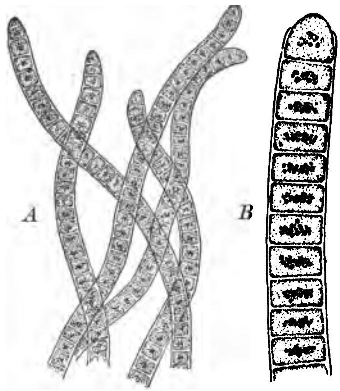


FIG. 173. *Oscillatoria*

A, tips of several plants; *B*, part of one plant, enlarged to show cellular structure. Both magnified, *B* much more than *A*

It is evident that blue-green algæ live and reproduce themselves in very simple ways.

205. The green algæ: *Pleurococcus*. This green alga is very widely distributed and is often called green slime, because of the appearance it presents when growing upon partially shaded tree trunks, fences, rocks, and old buildings. It is not usually recognized as being a plant. When there is abundant moisture in the air, the coating of plants presents the appearance of a coating of green paint upon the surface which supports them.

When examined under suitable magnification, the green slime is seen to be composed of many thousands of single-celled plants. A careful measurement of a number of plants showed their average diameter to be about $\frac{1}{2000}$ inch (.014 mm.). In other words, it would require approximately 500 of these

plants, placed side by side, to make a row that would reach across the unsharpened end of an ordinary lead pencil. How does *Pleurococcus* compare in size with average bacteria?

The spherical plants consist each of a small mass of living material, or protoplasm, surrounded by a cell wall. The protoplasm is so thoroughly colored by chlorophyll that usually it is not easy to see the centrally placed nucleus (fig. 174). Sometimes in these plants special parts of the protoplasm hold the chlorophyll, and each of these is known as a chloroplast, which means "a green body," or a chlorophyll-containing body. Parts of the protoplasm that surrounds the nucleus and the chloroplasts are granular and are called cytoplasm. Some of the internal space of this one-celled plant may be occupied by one or more vacuoles, which are regions surrounded by cytoplasm and filled with air or water.

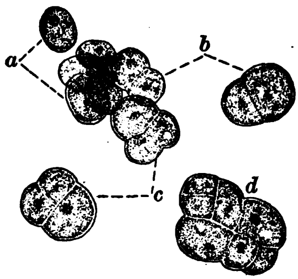


FIG. 174. Green slime (*Pleurococcus*)

a, single plants showing cell wall, granular cytoplasm, and nucleus; *b*, plants in process of reproduction by division, or fission; *c* and *d*, further divisions sometimes resulting in formation of colonies of plants. Greatly enlarged

206. The food of *Pleurococcus*. The bark or other substance upon which *Pleurococcus* grows is often sufficiently moist to provide it with water. Rains and dew supply water intermittently. When dry, the plants remain dormant until conditions again become favorable. Carbon dioxide (and possibly some moisture) may be absorbed directly from the air, and with carbon dioxide and water, and favorable temperature and light, *Pleurococcus* plants may carry on photosynthesis, thus making their own foods. Heat, cold, and extreme drought are some of the severe conditions which this plant must be able to resist in order to live. When plants from any of these extreme conditions are placed in favorable moisture, temperature, and light, they become bright green within a few hours, showing that they are manufacturing foods.

207. Reproduction of *Pleurococcus*. New *Pleurococcus* plants are formed by the division of the old plants. Thus, the growing, or vegetative, plant body (one cell) divides, and each division is a new plant. Under favorable growing conditions reproduction goes on rapidly. The divisions follow one another in such a way that whole colonies, the descendants of one individual, are often grouped together (fig. 174). Obviously *Pleurococcus* is a very simple plant in its structure, nutrition, and reproduction.

208. *Spirogyra*. One of the most abundant of the common floating pond scums is the green alga, *Spirogyra*. The plant is sometimes called "brook silk" because of its soft, silken texture, by means of which it may generally be distinguished from other fresh-water algæ. It is usually very bright green, except when it gathers in dense masses at the surface of the water, when it may be dark yellowish green. *Spirogyra* is a many-celled plant, with cylindrical cells arranged end to end, and all held in a common sheathing plant wall. Also, each cell contains one or more peculiar spirally arranged chloroplasts, each of which extends almost or quite the entire length of the cell (fig. 175). There are different numbers of chloroplasts in the cells in different species of *Spirogyra*. A layer of cytoplasm usually lies just within the cell wall, and strands of cytoplasm run to the nucleus, which is suspended in the central part of the cell (fig. 175).

209. The nutrition and growth of *Spirogyra*. In the water in which *Spirogyra* lives there are dissolved the carbon dioxide and other inorganic materials from which foods are made. Indeed, there is much water within the plant itself, as may be demonstrated by careful drying, by which it is sometimes found that as much as 98 per cent of this plant is water. That photosynthesis is carried on is often made evident by the oxygen bubbles which arise from the plants that are active. It is obvious that this plant can expose more chlorophyll to the light, and hence can do more photosynthetic work, than can *Pleurococcus*.

When *Spirogyra* cells divide, the division wall is at right angles to the length of the plant. This results in an increase in the number of cells and usually in the growth in length of the whole plant. Growth occurs so rapidly that, in a few days after the plants are first seen in the spring, they become so abundant that they pollute the water in which they grow, and it is often necessary to remove these and other algæ, as is seen later (sect. 216).

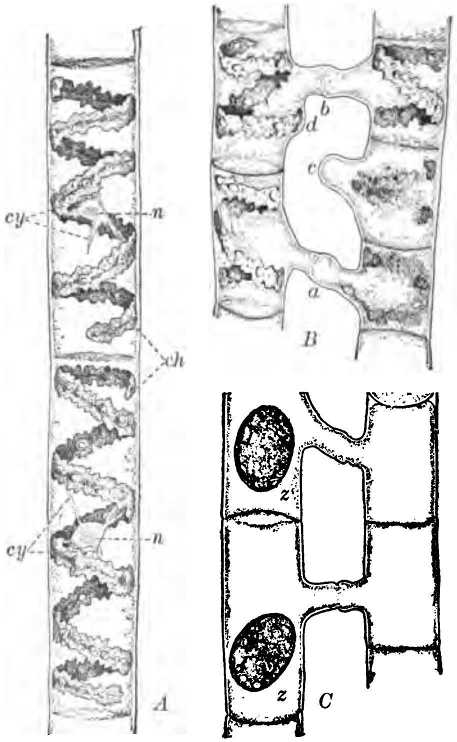


FIG. 175. *Spirogyra*

A, a vegetative cell, showing the form of the cell and of the spiral chloroplast (*ch*), also the nucleus (*n*) and cytoplasm (*cy*); *B*, beginning of conjugation (*a* and *b*), and tubes which failed to conjugate (*c* and *d*); *C*, completed zygospores (*z*)

210. The reproduction of *Spirogyra*. It is possible for a single plant to become broken into two or more pieces, when each one may grow into a new plant; this is vegetative reproduction and resembles the vegetative reproduction that was seen in *Pleurococcus*. But this is not the usual method of reproduction in *Spirogyra*. The cells of two plants that lie near one another may unite in pairs by means of tubes growing out from the walls of both of the uniting cells (fig. 175). These tubes meet and their end walls are absorbed, so that there is a continuous tube

from one cell to the other. Then the protoplasm from one cell passes through this tube to the other cell, and the two masses of protoplasm unite. The nuclei unite and one cell is formed from what were two. About this new cell a heavy wall is formed, and this specially formed structure is a *spore;* that is, a specially formed cell which can reproduce the kind of plant that formed it. It must be noted also that this spore, being formed by cell union and not by cell division, is sexual; also, sexual cells that are formed by union of similar cells are called *zygospores*, that is, yoked spores. It is customary to speak of the cells that unite to form spores as *gametes*, and in the case of the plant *Spirogyra* the gametes are similar, so there need be no special name here for the two gametes, to distinguish them one from another. In asexual reproduction, as will be seen in other plants, reproduction is carried on by means of spores that are formed by cell division, not by cell union.

In two *Spirogyra* plants there may be many cells uniting, or conjugating, at the same time. These pairs are usually in about the same stage of spore formation. Occasionally cells from one plant will unite with those from more than one other plant. Also, occasionally one cell may unite with the adjoining one in the same plant. When ripe, the zygospores are set free by the decay of the old walls and may fall to the bottom of the pond or stream. After a period of rest, sometimes after a drought or in the spring, these spores germinate and produce new *Spirogyra* plants. It is obviously an advantage to the plant to have a heavy-walled spore to carry it through unfavorable periods.

211. A branching alga: *Cladophora*. This is a green alga of very wide distribution. It usually grows attached to objects along shoals in streams, over dams, and about waterfalls. Sometimes it appears in heavy floating mats along margins of ponds, lakes, and even oceans. It is one of the few green algæ ever found in salt water. *Cladophora* is extensively branched (fig. 176), and since its branched filaments are abundantly supplied with chlorophyll, it is clear that this

plant is well fitted for much chlorophyll work, and consequently abundant food manufacture. It grows with remarkable rapidity. A *Cladophora* plant sometimes becomes broken into two or more pieces, when each may grow into a new plant; or at times the cells divide and form many small swimming spores, each of which may grow into a new plant.[1]

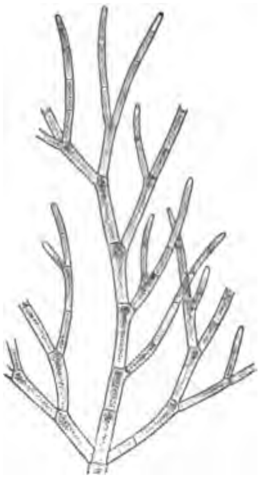


FIG. 176. A branching alga (*Cladophora*)

This plant, but a small part of which is here shown, often forms great mats of growth which cover the rocks and sticks upon which it grows. After Collins

212. *Vaucheria:* habitat and structure. *Vaucheria* is commonly called "green felt," a name which suggests the characteristic appearance which it presents as it grows upon the moist surface of the earth, in pots, on growing tables in the greenhouse, or upon damp, shaded soil out of doors. It also grows in pools of water, where it is distinguished from many other algæ by its coarseness. Certain species of *Cladophora* are coarser than *Vaucheria*, but their greater length and more extensive branching will ordinarily enable one to distinguish them. Plants that have been kept in a dish of water in the laboratory for a few days grow into a heavy, moss-like mass and are good material for study. The plant branches considerably (fig. 177), and the newest branches are the greenest and most active. The older portions may die, thus separating the branches from one another so that new individuals are formed by vegetative reproduction. No cross walls appear in the vegetative part of the plant, and all the cells are within the tubular wall of the plant.[2]

[1] For details of reproduction by spore formation, see *Cladophora* and *Ulothrix* in Bergen and Caldwell, Practical Botany, or Bergen and Davis, Principles of Botany. [2] Such a plant is called a *cœnocyte*.

213. *Vaucheria*: nutrition. Materials for food-making may be absorbed from the moist earth or from the water in which this plant grows. The abundant chlorophyll suggests considerable ability to manufacture its own nutrient substances, but this plant is not so well fitted for securing abundant exposure to light as is *Cladophora*. It is to be noted that, living on the land as these plants often do, they do not have the protection against extremes of light and temperature that water algæ enjoy.

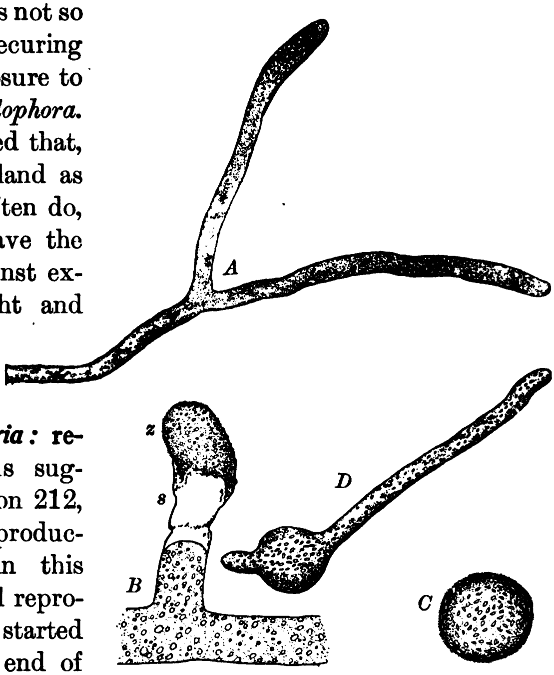


FIG. 177. *Vaucheria*

A, branch of a vegetative plant; *B*, branch forming zoöspore; *z*, young zoöspore just emerging from the sporangium (*s*); *C*, a free zoöspore; *D*, zoöspore germinating to form a new plant

214. *Vaucheria*: reproduction. As suggested in section 212, vegetative reproduction occurs in this plant. Asexual reproduction may be started by having the end of a branch cut off by a cross wall. The part that is thus cut off proceeds to form a large reproductive body (fig. 177, *B*, *C*); the wall which surrounds it breaks, and after a period of swimming it germinates and forms a new plant (fig. 177, *D*). This special reproductive body is called a *zoöspore* (animal spore), or swimming spore. The formation of zoöspores may be induced in the laboratory by keeping *Vaucheria* plants in a dish of shallow water.

Another kind of reproduction may occur at the same time that zoöspores are being formed, though it usually occurs at other times. Upon the sides of the plant special short branches are formed. Two kinds of branches arise near one another (fig. 178). One is short and irregularly spherical, and has a beak. This branch forms one large cell within it. The other branch is longer, somewhat coiled, and has a terminal cell that is cut off by means of a cross wall. In the terminal segment many small cells are formed. Through a small opening in the tip of this coiled branch these cells escape, some of them entering the beak of the other branch and one of them uniting with the large cell. This union forms a spore which proceeds to develop a heavy protecting wall. After a period of rest this spore germinates and produces a new plant.[1]

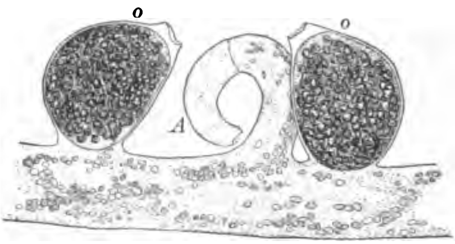


FIG. 178. The sexual reproductive structures of *Vaucheria* (*V. sessilis*)

o, oögonia; *A*, antheridium. Note the opening in the antheridium for exit of sperms, and in the oögonia for their entrance to the large eggs. Greatly enlarged

If this spore had been formed by the union of similar gametes, as in *Spirogyra*, we should have called it a zygospore; but it is formed by the union of gametes that are very unlike, — one large gamete (the *egg*, or *oösphere*) and the other a small gamete (the *sperm*), — and the resulting spore is called an *oöspore*, which means "egg spore." When similar gametes unite to form a zygospore, the process is called *conjugation*, but when dissimilar gametes unite to form an oöspore, the process is called *fertilization*. The special sex organ which produces the sperm is the *antheridium*, or sperm case, and that which produces the egg is the *oögonium*, or egg case.

[1] TO THE TEACHER. No attempt is made to present the difficult and technical questions relative to the alternation of generations in the thallophytes.

Vaucheria has three methods of reproduction — vegetative, by asexual spores (zoöspores), and by sexual spores (oöspores). One plant may use vegetative reproduction at one period of growth, asexual spore reproduction at another, and sex spore reproduction at another, but two methods are rarely used at the same time.

215. Other green algæ. Although in inland waters green algæ are more abundant than all others, only two other genera will be mentioned in this connection. *Sphærella*, a unicellular form somewhat like *Pleurococcus*, is frequently found in stagnant water. It sometimes grows so luxuriantly in barnyard and roadside pools as to give the water a bright green appearance, and its resting spores may impart a dark red color to drying pools in which the plants have flourished. *Chara*, or stonewort (fig. 179), is a complex alga that is found in great abundance on the bottoms of shallow lakes and streams throughout the continent. It has a heavy coating of calcareous material, which, as the plant dies, falls to the bottom of the pond or stream. *Chara* grows in such luxuriance that its deposits eventually form deep layers of this calcareous material, or marl, as it is called. Marl has been found of great value as one of the materials used in the manufacture of cement, and not a few of the lakes in which *Chara* grows are dredged to secure the marl deposits for this important manufacture.

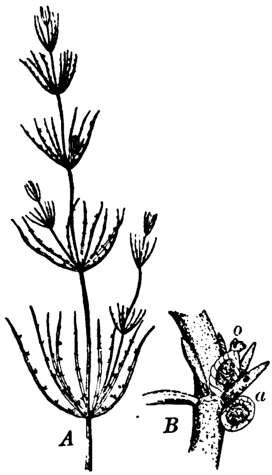


FIG. 179. The stonewort alga (*Chara*)

A, a slightly magnified piece of a plant, showing the general appearance; *B*, a more highly magnified illustration showing the oögonium (*o*) and the antheridium (*a*), by means of which reproduction takes place

216. Algæ and water supply. Many of our large cities have found it advisable to adapt or construct reservoirs for water supply. These are open pools, lakes, tanks, etc., and they are

intended to hold water enough so that there will be a sufficient supply in times of scarcity. Such reservoirs have proved so admirable as growing places for algæ that these plants often become a nuisance. Their presence in water for domestic use is not attractive, and, besides, they may stop up the water pipes. But far more serious than these objections is the actual pollution of the water because of their presence. When they die they become the food for decay-producing organisms, and often positively injurious substances are generated. It has been found that by towing about in such reservoirs a quantity of copper sulphate inclosed in coarse sacking, minute quantities of the salt become dissolved and the algæ are thus killed. The solution is not strong enough to render the water unwholesome for use. This treatment has been an important factor in improving the water in many American cities.[1]

217. The brown algæ. The remaining groups of algæ, though almost exclusively salt-water plants, have such striking characteristics that brief mention of them must be made, and pupils who live near the seacoast will be interested in extending this study. The brown algæ, or brown seaweeds, are found along the shores of all the oceans. They grow attached, by means of strong holdfasts, to rocks, piling, or any relatively fixed support that is available.

From high-tide mark to a little below low-water mark certain brown algæ, known as rockweeds (*Fucus* and *Ascophyllum*) (fig. 180), often form dense coatings upon rocks. At low tide these rockweeds hang loosely over the exposed rocks, and exhibit the characteristic dark olive-green color.

The brown algæ sometimes become detached and are carried hundreds or even thousands of miles from their original

[1] See "A Method of Destroying or Preventing the Growth of Algæ and Certain Pathogenic Bacteria in Water Supplies" and "Copper as an Algicide and Disinfectant in Water Supplies," *Bulletin 64* (1904) and *Bulletin 76* (1905), respectively, Bureau of Plant Industry, U.S. Dept. Agr.; also Whipple, Microscopy of Drinking Water, chap. xii, John Wiley & Sons, New York, 1906.

growing places. This is true in the case of *Sargassum*, some species of which thrive along the shores of tropical oceans. In the North Atlantic Ocean, north of the Canary Islands, is a body of water known as the Sargasso Sea. Its entire area is more or less filled with floating *Sargassum* and other forms of plant and animal life. *Sargassum*, like some other brown algæ, is peculiarly fitted for floating by the presence of "air bladders," which are swollen portions of the leaf-like expansions of the plant. In mid-ocean one may see small floating masses of these plants, which have been carried sometimes hundreds or even thousands of miles from their original homes.

FIG. 180. Rockweed (*Fucus*)

A, the base of a young plant, showing an early stage in formation of the holdfast, which attached the plant to a piece of wood. *B*, tip of a plant; *b*, air bladders; *a*, specialized regions in which reproductive organs are formed; *c*, new leaf-like growth where the plant has been broken. A little less than natural size

218. The kelps. The giant kelps belong to the brown algæ. The cylindrical, stem-like plants sometimes (as in *Macrocystis*) reach a length of from 800 to 900 feet, while "devil's apron," (*Laminaria*) grows into strap-like or widely spread, tough, leathery expansions. All of these forms have heavy, root-like holdfasts, which are so strong that the plant will usually break elsewhere before it will pull away from its support.

At one time the world's supply of iodine was derived from the brown algæ; now it can usually be prepared more economically by chemical means. Soda was formerly secured from these plants, but chemical processes have driven out the laborious methods of securing that substance directly from plants. Gelatinous foods and a sugar known as mannite are secured from some species of brown algæ. In some coastal

portions of this country the farmers collect and carry inland great quantities of brown algæ and spread them over the cultivated land as a fertilizer.[1]

FIG. 181. A red alga (*Dasya*)

219. The red algæ. The red algæ grow mostly in deeper water than do the brown algæ. They are almost wholly confined to salt water.

The marine forms of this group present most striking shapes and colors. They are of different shades of red, varying from the most brilliant to those that are dark and somber, while

[1] For the reproduction of the brown and red algæ, see Bergen and Davis, Principles of Botany.

some are a deep purple. Chlorophyll is present, as in all other algæ, but is often completely obscured by the other colors. Sometimes all the colors are obscured by coatings of calcareous material.

The red algæ have basal holdfasts. The plants are extensively branched (fig. 181) and, as a rule, are smaller and more delicate than the brown forms.[1] The entire plant often looks like a sparsely branched stem with many finely divided leaves. The gelatinous material obtained from certain of the red algæ is by some regarded as a delicacy. In the North Sea and elsewhere in the Atlantic Ocean occurs a red alga known as "Irish moss," which is collected in large quantities and employed in the preparation of jelly, to be used both directly as food and as a basis for the preparation of other foods.

PROBLEMS

1. Why are the blue-green algæ on the whole considered to be of lower organization than the green algæ?

2. Which of these groups is more injurious in its effect on reservoirs of drinking water? Why?

3. Why is it often found desirable to build roofs over such reservoirs?

4. In what ways do algæ help or hinder the life of aquatic animals? How does an aquarium aid in answering this question? What bearing on it has the fact that the flinty cell coverings of some of the microscopic algæ (diatoms) are found in the digestive cavities of oysters?

5. What algæ are used as human food?

6. May polishing powders or pastes be made of fossil remains of algæ? Use a compound microscope in examining some such powders.

7. It is generally supposed that algæ were among the first plants to appear on the earth in very early geological times. Does this seem probable?

8. How do the algæ pass through the winter and seasons of drought?

[1] The best way for the teacher to give a general notion of brown and red algæ is to secure card mounts or bottled material for class demonstrations of a few of the leading types in each group. These may be obtained from the Woods Hole Biological Laboratory, Woods Hole, Massachusetts, and from other reliable supply houses. Well-prepared card mounts preserve the natural colors, and may be kept indefinitely for laboratory use.

CHAPTER XVI

FUNGI AND FUNGOUS DISEASES OF PLANTS

220. The fungi as dependent plants. In our earlier discussion of plant nutrition it was found that green plants possess chlorophyll, by means of which they make their own foods. Every observant person who has had any considerable experience with plants has noted several or many kinds, as mushrooms and molds, that do not possess chlorophyll. These chlorophyll-less plants cannot manufacture foods from water and carbon dioxide, and hence are dependent. Their dependence appears in various relations between them and the host plants or animals that supply them the requisite food. Sometimes they live upon or within living plants or animals, being known as *parasites*; or they may live upon dead nutrient substances, when they are known as *saprophytes* (fig. 182).

FIG. 182. An old pine stump upon which the fungus *Polyporus* is growing

There are many common fungous parasites, as wheat rust, potato blight, and tree-destroying fungi. Our economic crops are greatly reduced in value every year through the destructiveness of these parasitic plants. Fungous saprophytes are also very abundant, the best-known being molds, mushrooms, and puffballs. In almost any deeply shaded, moist, and warm

undergrowth one may find large numbers of these saprophytic plants growing upon decaying organic matter. By breaking open an old log or branch of wood (fig. 183) upon which fungi are growing, or by upturning rich soil, one often finds the extensively interwoven, mold-like saprophytic growth. This internal growth gathers nourishing material for the whole dependent plant, and at the same time helps to bring about the decay of the material upon which it lives.

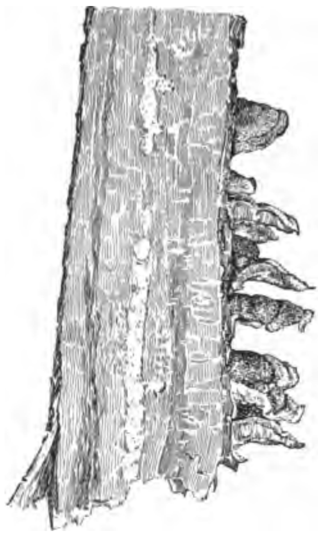


FIG. 183. A section through a dead branch of a cottonwood tree

Note the white patches of internal mycelium and the external spore-producing bodies of the fungus, a *Polyporus*

221. The algæ-fungi. There are many different groups of fungi, and they are often so unlike that it is at first hard for the student to regard them as belonging to the same larger group, the fungi. In the case of some of the molds, if the thread-like fibers of which they are composed were to possess chlorophyll, they would appear quite similar to some of the algæ. Because of this structural resemblance one group of fungi is called the algæ-fungi (*Phycomycetes*, meaning "algæ-fungi"), that is, fungi that are more like algæ than are other fungi. Most of the saprophytic molds and a good many destructive parasites belong to the algae-fungi. A few types will show their nature, how they live, and how they affect the things upon which they live.

222. Bread mold. If a piece of slightly moistened bread is placed in a glass jar or in a covered dish for a few days, an abundant supply of mold soon appears upon it. Several kinds of molds may develop at the same time under such conditions, but the common bread mold, or black mold, is the one which

usually appears. It grows in and about our homes in great abundance, upon bread, fruits, and other favorable nutrient substances that are left exposed. When young the mold is white, only assuming its blackish appearance when spores are formed.

223. Vegetative structures, and nutrition of bread mold. A mass of growing bread mold is composed of many white threads grown together until they have become closely interwoven. Each thread is called a *hypha* (" a single web "), and the whole network of hyphæ is the *mycelium*, or fungus mass.

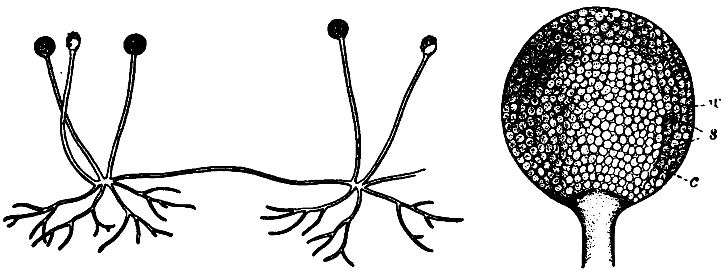


FIG. 184. Bread mold

At the left is a slightly magnified illustration of plants, one of which has given rise to the other by means of a runner, or stolon. Descending are the rhizoids and ascending are the aërial branches, upon the tips of which spores are borne within sporangia. At the right a more highly magnified sporangium is shown. Its wall (*w*) incloses many spores (*s*), through which may be seen the columella (*c*), which is the swollen tip of the stalk upon which the sporangium is borne. This wall may be broken away, so as to leave some of the spores lying upon the columella, as is seen in two cases of the plants shown at the left

Careful examination also shows that some of the hyphæ have grown down into the bread, and if one could see through the bread after mold has grown on it for a few days, much of the mycelium would be seen within it. Branching downward from some of the superficial hyphæ are special root-like hyphæ (*rhizoids*) (fig. 184), which descend and spread within the nutrient material. At such places upright hyphæ also are formed. Long, runner-like branches (*stolons*) may extend over the surface a little way. From the stolons a new set of rhizoids and upright hyphæ may grow.

Under magnification the hyphæ may be seen to consist of heavy, tubular cell walls, in which the granular protoplasm is not separated into distinct cellular divisions by transverse walls, as it is in most of the algæ.

Bread mold lives upon and within its nutrient substance and absorbs food material directly from it. Parts that are in contact with the sub-stratum do the work of food absorption. Food is carried through the tubular cells to the parts of the mycelium that are above the food material. Since nutrient material is secured in ready and abundant supplies, the growth and extension of the mold is usually quite rapid.

224. Effect of mold upon bread. If a piece of bread upon which mold is growing vigorously is kept moist, much of the bread is consumed by the mold, but usually the mold will not continue to grow until the bread is completely consumed. Either because it has secured all the food it can extract from the bread, or because it has secreted substances that prevent its further growth, or because it is unable to hold its own with other organisms (molds and bacteria), the bread mold after a time ceases to grow. Other molds and bacteria may appear, one kind following another for weeks, until the decay of the bread is almost or quite complete.

If the mold, and the material upon which it grows, is kept tightly sealed, growth stops before all the food material is used. Molds often grow for a time in jars of fruit, forming upon the top of the fruit a coating which remains until the jar is opened. If this coating is removed and a fresh supply of air is admitted, a new growth soon appears, and if a constant supply of air is maintained, various molds may grow until all the fruit is destroyed.

225. Reproduction of bread mold. In addition to vegetative reproduction by means of stolons, this mold also reproduces itself both asexually and sexually. Upon the ends of upright hyphæ, sporangia are produced (fig. 184). In the development of the sporangia, first a transverse wall cuts off a small tip of the upright stalk. This tip cell grows rapidly until it

has become a large, spherical body. Meanwhile the transverse wall has extended into the spherical sporangium, thus producing a little column (the *columella*), upon which the sporangium contents rest. The protoplasm of the sporangium divides into many small spores, which, when the sporangium wall breaks, are scattered widely into the air. The musty odor which is detected when we smell mold may be due to the presence of large numbers of these spores or to gases that have been produced within the nutrient material.

FIG. 185. Grape leaf with grape mildew

A leaf of the grape, upon which may be seen the white, fluffy patches of grape mildew. Photograph by H. H. Whetzel

If bread that has not been exposed to the air is cut in a room in which the air is quiet, and if one piece is covered directly in a glass dish, another similarly covered after five minutes' exposure to the air of the room, and another after five minutes' exposure on the outside window sill, an interesting test of the abundance of spores in the atmosphere will be afforded. One class of students, in performing this experiment, secured the development of mold upon all three pieces of bread, having in all five kinds of mold. Another class used sterilized gelatin culture material and exposed it to the air of a schoolhouse hallway for five minutes, and during the following week there grew upon the gelatin eight different kinds of molds and bacteria. Juices of fruits, as prunes, are also good nutrient materials for experiments in growing molds.

In addition to reproduction by asexual spores, sexual reproduction sometimes occurs. Tips of branches unite and form heavy-walled zygospores, somewhat after the manner of zygospore formation in *Spirogyra.*

226. The grape downy mildew. It is not uncommon to see the white patches of downy mildew upon the leaves of the grape (fig. 185), and sometimes it appears upon the green shoots and the fruit. In the central states, supposed to be the original home of this parasite, it has been an injurious pest for many years. In some localities it well-nigh destroys the grape crop at times, but when conditions are thoroughly favorable to the vigorous growth of grape plants, the mildew does not seriously interfere with the crop of grapes. When plants which are attacked by the parasite are properly sprayed, the ill effects may be reduced or prevented. The spray kills spores which are upon the leaf's surface.

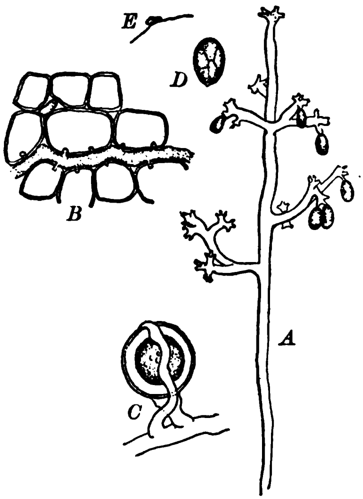


FIG. 186. Grape mildew (*Plasmopara*)

From the mycelium within the cells of the grape leaf, haustoria (*B*) are formed. Upright hyphæ (*A*) bear conidia. These conidia divide, as at *D*, and form zoöspores (*E*). Within the leaf, oöspores (*C*) are formed. After Duggar

227. Structure and nutrition of grape mildew. The surface patches that are characteristic of downy mildew are not produced until some time after the leaves have had the parasite growing within them. The threads, or hyphæ, grow between the cells of the leaf, and through the walls of these cells there grow short branches (*haustoria*), which absorb food directly from the cell contents of the host plant (fig. 186, *B*). Thus the parasite may grow by means of the food material made

by the grape leaf, until the fungus permeates the entire leaf. If the leaf is not able to make a surplus of food material, the amount taken by the parasite may result in the starvation and death of the grape leaf. Possibly, also, the parasite may excrete substances that poison the host plant.

FIG. 187. Experiments in destroying potato blight

Photograph by the New York Agricultural Experiment Station illustrating the results of spraying potatoes to prevent disease. Those that were not sprayed yielded at the rate of 161 bushels per acre; those sprayed three times during the season yielded at the rate of 350¼ bushels per acre; those sprayed every two weeks yielded at the rate of 380 bushels per acre. In other experiments the results are even better. In this same station, during the year 1904, the average gain per acre in the yield for three sprayings is 191 bushels, and the gain for spraying every two weeks is 233 bushels

228. Reproduction of grape mildew. Sometimes the upright branches of aërial hyphæ of grape mildew produce rounded, spore-like bodies (*conidia*) (fig. 186, *A*). When these conidia come into favorable moisture (rain or dew) and temperature, they divide, each one forming several zoöspores (fig. 186, *E*). The conidia, therefore, act like sporangia, since they form asexual spores. The zoöspore may swim in the dew or rain for

fifteen or twenty minutes, and then lose its cilia and begin to grow into a new hypha of the mildew. These new hyphæ may grow through the stomata of leaves and start a new growth of the parasite.

Within the host leaf sexual reproduction of the parasite occurs, and oöspores (fig. 186, *C*) are formed. These oöspores are thought to reproduce the parasite in the following spring, when the decay of the host leaf releases them. Our knowledge of oöspore formation in grape mildew and potato blight is still incomplete. It is thought, however, by some special students of fungi, that potato blight has largely lost its power of sexual reproduction, and that oöspores are not often formed.[1]

229. Prevention of grape mildew and potato blight. Potato blight is a common and extremely destructive potato disease caused by a fungus that resembles grape mildew in its structure and habits of growth. It is readily and widely distributed and often causes serious losses by partially or almost completely preventing the growth of a potato crop. Both potato blight and grape mildew are prevented from reaching their normal growth, and are sometimes completely destroyed, by spraying with Bordeaux mixture.[2] It was in connection with a study of grape mildew that the Frenchman Millardet, in 1881, began experimenting with Bordeaux mixtures. He demonstrated the fact that this mixture, when properly used as a spray, will prevent most of the ill effects of grape mildew. The effect of using this spray in treating potatoes is well shown in figure 187. Many other destructive parasitic diseases of plants, though by no means all of them, may be prevented in the same way.[3]

[1] G. P. Clinton, "Oöspores of Potato Blight," *Science*, 744–747, 1911.

[2] The preparation as most commonly used consists of materials mixed in the following proportions: copper sulphate, 5 pounds; stone lime, 5 pounds; water, 50 gallons. Other proportions are often used, as indicated in agricultural experiment station reports.

[3] Duggar, B. M., Fungous Diseases of Plants. Ginn and Company, Boston, 1909.

"Potato Spraying Experiments in 1906," *Bulletin 279*, N.Y. Agr. Exp. Sta.

"Certain Potato Diseases and their Remedies," *Bulletin 72*, Vt. Agr. Exp. Sta.

Among the other algæ-fungi which cause common destructive diseases are those which cause the cranberry gall; the brown rot of lemons and other citrous fruits; the white, or downy, mildew of shepherd's-purse, the common radish, mustard, and turnip; and the downy mildew of cucumbers, pumpkins, watermelons, and lima beans.

230. The sac fungi. Some of the more common sac fungi are the cup fungi, the morel, the yeasts, and the mildews; the latter often appear upon leaves of plantain, smartweed, lilac,

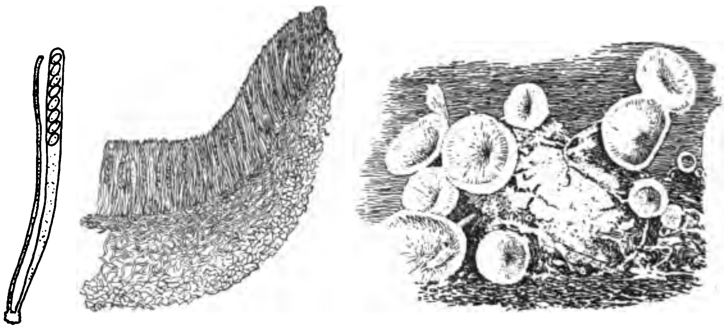


FIG. 188. Brown rot (*Sclerotinia*) growing upon old plums

At the right are some of the fruiting cups; in the middle is a greatly magnified portion of the cup, showing the spore-bearing areas; and at the left is one of the spore-bearing threads still more magnified, so as to show the spores. After Duggar

and oak. More fungi belong to this group than to any other, and since most of them are parasitic, it is evident that they are of great economic importance. They have wide variations in form and structure. Usually the parasitic sac fungi grow upon instead of within the host plant. From this superficial growth haustoria are sent into the tissues of the host plant.

As illustrations of the damage that may be done by members of this group we may cite the brown rot of peaches, plums, cherries, and apricots. Old dried fruits are sometimes found lying on the ground or still clinging to the trees. These "mummies" are a result of the brown rot. Sometimes they produce little brownish cups which are the spore-producing

structures of the plant (fig. 188). Most of the damage is done to the fruit before any of these cups appear; indeed, the fruit is worthless before the parasite has matured. Spores are distributed from the cups and new infection of fruit occurs, and thus the destruction is continued. The spores are formed within the tissues of the cup in the enlarged ends of hyphæ, and these enlarged spore-forming tips of the hyphæ are the sacs from which the group name *sac fungi* is derived. The sac is called the *ascus* (sac), and the group of plants is called the *Ascomycetes* (sac fungi). Brown rot seems to attack all kinds of stone fruits, and the total amount of damage done by it is enormous. In 1887 it was reported that the disease had caused a shortage of 800,000 baskets in the peach crop of Maryland and Delaware for that year. In 1900 Georgia lost about 40 per cent of its peach crop—a money loss of between $500,000 and $700,000.[1]

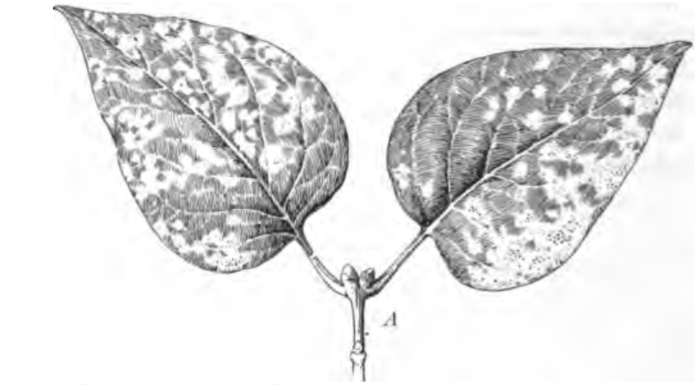
Fig. 189. A group of morel mushrooms

The disease may be checked by destroying the infected fruits and twigs. Spores are so generally distributed that spraying is also necessary. Different sprays have been used, but with such varying success that the advice of local experiment stations should be sought for the special needs in each state.

231. The morel. Another representative of the sac fungi is the morel mushroom (*Morchella*) (fig. 189). Its mycelium grows in earth that is very rich with decaying organic matter. It is usually found in woods, among the leaves and about old logs and stumps. The mushroom is the only part usually noticed, and under favorable conditions of moisture and

[1] "The Brown Rot of Peaches, Plums, and Other Fruits," *Bulletin 50*, Georgia Agr. Exp. Sta., 1900.

temperature it develops in a very short time, growing by means of food material that has been gathered by the underground growth. In the deep, wrinkle-bordered pits of the



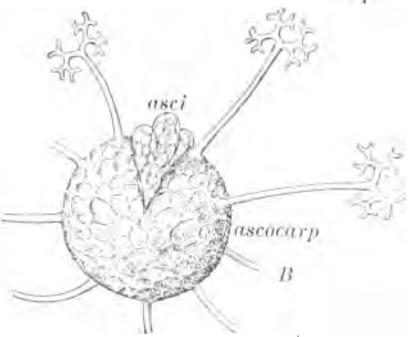


FIG. 190. Lilac mildew

A, leaves of lilac upon which lilac mildew appears in whitish patches; the small, dark reproductive bodies are also shown. *B*, the central, heavy-walled body (ascocarp) which contains the sacs (asci) in which spores are formed. Upon the wall of the ascocarp are stalks, sometimes called arms, which have peculiar branches at their tips. About 60 times natural size

mushroom are the spore-bearing hyphæ. The spores form in great numbers; they are very light and are easily carried long distances by currents of air. Most of the mushrooms do not belong to the *Ascomycetes.*

232. Lilac mildew. Mildews are frequently found upon the surface of leaves of lilac (fig. 190) and upon the willow, oak, some of the smartweeds, and many other plants. The fungus is a superficial parasite with haustoria penetrating the host cells.

At times upright hyphæ form conidia, and to their presence the powdery appearance of these mildews is largely due. The conidia, if favorably placed, are the means of producing new

growths of the mildew. Another complex method of reproduction results in forming a heavy-walled body, the *ascocarp*, so called because it is the body which contains the sacs and ascospores (fig. 190). In late summer the ascocarps may, without magnification, be seen as small black bodies upon the surface of lilac leaves. When the ascocarp is broken, the sacs and spores are exposed. From the walls of the ascocarp peculiar arms extend, and in the lilac mildew and some related mildews these have strikingly branched tips.

The heavy-walled ascocarp is resistant to unfavorable climatic conditions. It may pass through the winter and break open in the following spring, thus freeing the thin-walled sacs. Upon escaping from the sacs the spores may be blown or carried about and germinate upon new host leaves.

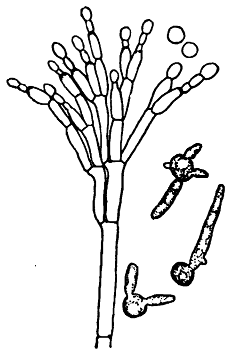


FIG. 191. The blue mold

At the left is the tip of a hypha, with the characteristic branches, on the ends of which are the spores; at the right are germinating spores. Much magnified. After Thom

233. Blue mold or green mold. When old shoes, gloves, or other articles made of leather are left in damp, warm places, a blue or green mold (*Penicillium*) frequently develops upon them. This mold also grows upon old lemons and oranges, and upon cheese. Various species have distinctive shades of color, so that the common names of *blue mold* or *green mold* can be taken only as applying in a general way. Certain species of *Penicillium* are said to give characteristic flavors to the cheese in which they grow, as *Penicillium Roqueforti* of Roquefort cheese and *Penicillium Camemberti* of Camembert cheese. These species are widely distributed and are found growing upon many substances besides cheese.[1] *Penicillium*

[1] An interesting discussion of various species and their cultural reactions is "Cultural Studies of Species of *Penicillium*," by Charles Thom, Ph.D., Mycologist in Cheese Investigations, *Bulletin 148*, Bureau of Animal Industry, U.S. Dept. Agr., 1910.

is a sac fungus which has almost lost the habit of reproduction by means of ascospores, the sac being rarely formed. It reproduces itself very abundantly by means of conidia (fig. 191). The number of these conidia is often so large that when the substance supporting the plants is slightly shaken, a small cloud of spores arises.

234. Yeasts. The yeasts constitute a group of plants of somewhat doubtful classification. Since they occasionally form sacs in which spores are formed, they are often classed with the sac fungi. They are extremely simple, and are more interesting because of their manner of life than because of their structure. A yeast plant is a single cell (fig. 192). It usually reproduces itself by a method of vegetative reproduction known as *budding.* The buds, before becoming separated from the parent cells, may bud again and again until a chain of plants is formed. If a cake of commercial yeast is examined, it is found, in addition to the large starch grains nearly always occurring in yeast cakes, to consist of hundreds of thousands of yeast cells, some single and some in process of budding. If a cake of yeast is kept at room temperature, the plants soon continue their growth, and other organisms (bacteria and molds) also grow, so that the yeast "spoils."

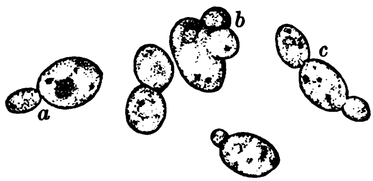


FIG. 192. Yeast plants

a, a plant from which a bud has begun to grow; *b* and *c*, plants with two buds. Note the vacuoles in the plants. Greatly enlarged

When yeast plants are placed in dough, they grow with great rapidity. They live upon the solutions in the dough, and in so doing they break down the sugar, thus forming from it small quantities of alcohol and carbon dioxide. The carbon-dioxide gas forms air spaces which cause the phenomenon known as *rising.*[1] During the process of baking, the air spaces

[1] Salt-rising bread owes its peculiar quality to the fact that, instead of yeasts, certain bacteria produce fermentation within the dough.

are enlarged, and at the same time the alcohol is evaporated. By former methods of bread-making pure cultures of yeast were less likely to be secured, wild yeasts very frequently appearing. By modern methods, quite similar to those used in bacteriology, pure cultures may be obtained, and it is therefore possible to secure the exact kind of fermentation of the dough that is desired.[1]

The processes of fermentation by yeasts are used in the manufacture of alcohol, wine, beer, and other liquors which contain alcohol. Certain definite kinds of yeast produce certain kinds of alcoholic fermentation, and it is necessary for the brewer to keep pure cultures of the desired yeasts in order to insure the particular quality of his product. In 1856 the great French scientist, Louis Pasteur, succeeded in devising methods of pure culture by isolating single yeast plants and growing a colony from each. Thus the particular result to be secured could be determined by the kind of yeast selected for use in fermentation. It was this method of pure culture which opened the way for many of the modern bacteriological investigations.[2]

235. The lichens. This is a group of plants of peculiar habits and structures. Often members of the group may be seen adhering closely to the bark of trees (fig. 193) or to the surface of rocks. They also appear upon the soil in great abundance. Sometimes they hang from branches of trees in ragged gray masses (fig. 194) that look somewhat like the common Southern hanging seed plant known as Florida moss.

[1] An especially interesting paper is "Bread and the Principles of Bread Making," by Helen W. Atwater, *Farmers' Bulletin 112*, U.S. Dept. Agr., 1910.

[2] The following citations will indicate a few of the many plant diseases that are caused by sac fungi.

"Root Rot of Tobacco," Annual Report, Conn. Agr. Exp. Sta., 1906.

"Peach Mildew," *Bulletin 107*, Colo. Agr. Exp. Sta., 1906.

"Wilt Disease of Cotton, Watermelon, and Cowpea," *Bulletin 17*, Division of Vegetable Pathology, U.S. Dept. Agr., 1899.

"Black Knot," *Bulletin 81*, Cornell University Agr. Exp. Sta., 1894.

"The Bitter Rot of Apples," *Bulletin 44*, Bureau of Plant Industry, U.S. Dept. Agr., 1903.

Although usually grayish green in color, some of the lichens are yellow, red, brown, or even black. Lichens can endure severe drought, cold, and prolonged exposure to intense light and to strong winds; hence it is evident that they can live under conditions which would be destructive to most kinds of plants. On account of this ability to undergo severe conditions, lichens are found at as great altitudes and throughout as great a range north and south as are any plants. They may remain dormant through long periods of unfavorable weather and, when favorable moisture and temperature return, almost immediately assume the greenish appearance which indicates their renewed activity. The lichen known as reindeer moss is brittle and pallid when dry, but when moist, it is green and soft.

FIG. 193. A common lichen (*Parmelia*) upon the bark of the shagbark hickory

Note the expanded and flat part of the lichen, also the cups in which spores of the fungus part of the lichen are formed

Those lichens which adhere very closely to their support and are scale-like are called *crustaceous;* those that adhere less closely and are leaf-like are *foliose;* and those that branch and are partially free from their sub-stratum are *fruticose.* Foliose forms are common upon rougher-barked trees and upon old fences, crustaceous forms grow upon smooth-barked trees and upon stones, while fruticose forms grow upon the ground or hang from branches of trees.

236. The structure of a lichen. A lichen is not a single plant, but a combination of fungi and algæ living together in such a close relationship that it looks like a single plant. There may be many individual fungi and many individual algæ in this relation, but the combination is spoken of as the lichen plant. The fungal part of the lichen is usually, though not always, a member of the sac-bearing class of fungi, and

FIG. 194. The "bearded moss" lichen (*Usnea barbata*) growing upon the branches of a spruce tree

consequently lichens are often classified with sac fungi. This is obviously a somewhat questionable classification, but for lack of a better one we shall use it. The algæ that enter into the formation of lichens are usually unicellular forms resembling *Pleurococcus*. When the lichen is dissected, the green cells of the algæ and the white threads of the fungi may be seen (fig. 195). The chlorophyll of the algæ enables the lichen to manufacture carbohydrate foods. Individual alga cells are often closely wound about by threads of the fungus;

these threads absorb food from the algæ. The fungus seems to hold the combination in compact form and to enable it to secure a foothold in places where neither the alga nor the fungus could live alone. In the lichen we have therefore a combination of plants — an alga and a fungus — neither of which alone could live long under the conditions of extreme exposure in which lichens are often found.

237. Economic significance of lichens. As lichens live in exposed rocky places, they serve to bring about the first stages of soil formation by the decay of old lichen plants and by the breaking up of the surface layers of the rock or other material

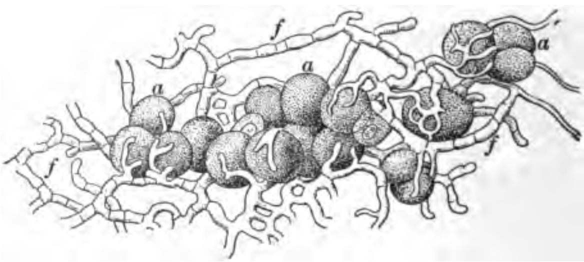


FIG. 195. A small piece of the interior of a lichen, showing the relation of the alga (*a*) and the fungus (*f*)

Magnified 500 diameters. After Bonnier

upon which they grow. Weathering processes also assist in crumbling the rock, and after a time there is soil enough to permit the growth of larger plants. Several kinds of crustaceous lichens are usually the forerunners of other vegetation in rocky regions which will not permit other forms of vegetation to live. The time required to produce enough soil for the growth of other plants depends largely upon the nature of the rock and the climate. It is said that on some lava beds, after almost two hundred years from their formation, crustaceous lichens are still in some places the only plants to be found. Lichens are important as food for herbivorous animals in regions where other kinds of food are scarce or where for a part of the year other vegetation is not available.

Reindeer moss (*Cladonia rangiferina*) is eaten in winter by animals, which find it green and nutritious when they remove the snow from above it. A few lichens are used as food for men, though they are not especially nutritious. A mucilaginous and starchy food is prepared from *Cetraria islandica*, a lichen which is known as Iceland moss. In Sweden *Sticta pulmonacea*, a very bitter lichen, is sometimes used as a substitute for hops in processes of brewing. Various dyes are prepared from lichens and are known in the markets as *orchil* and *cudbear*, but these are not so commonly used as formerly. *Litmus*, used in preparing litmus, or blue-test paper as a test for the presence of acids, is also prepared from lichens.

FIG. 196. Corn smut

An ear of corn, part of which has been destroyed and replaced by a mass of smut spores. Photograph by Kern, Pennsylvania State College

238. The basidium, or stalk fungi. The sac fungi were so named because the spores are formed in a sac. In like manner the basidium, or stalk, fungi (*Basidiomycetes*) are so called because the spores are formed on the outside of the tip of a hypha known as the stalk, or basidium. Within this division of fungi several sub-divisions are recognized. One of these, the *smuts*, is represented by forms that frequently appear upon the ears of corn (fig. 196) and upon heads of oats (fig. 197), wheat, barley, and other

members of the grass family; another sub-division is the ***rusts,*** found wherever wheat and oats are grown, and also appearing upon many other host plants; ***mushrooms*** and ***puffballs,*** another sub-division, are widely distributed wherever there is a good supply of decaying organic matter, and some grow as parasites upon living trees. Because of the frequency of the parasitic habit in the stalk fungi, it is evident that the group is one of great importance to industries that depend upon the growth of plants.

FIG. 197. Smut on the oat plant

Two heads of oats, each with the leaf (*l*) which sheathes the stalk. The head at the left has matured its grains in a normal manner, while in the one at the right the grains are supplanted by the blackened masses of the smut. One third natural size

239. Damage from smuts. The cereals are particularly affected by these parasites, since all of the smuts are parasitic and since the grains seem to be especially favorable hosts for them. Different writers present very different estimates of the amount of damage done to our crops annually by these parasites, but a conservative estimate made by the United States Department of Agriculture states that the loss from smut in wheat, oats, and barley exceeds $25,000,000 annually, and that the loss in oats alone exceeds $6,500,000. The damage to corn is probably about equal to that of oats. Some writers estimate the loss to our crops as several times greater than the above conservative estimates. Whatever may be the exact loss, it is evident that the matter is one of great significance.

240. Corn smut. This smut (*Ustilago maydis*) is ordinarily first noticed when it forms whitish masses in the ear or tassel or upon other parts of the corn plant. These masses develop into spores and become black, sticky, and unsightly. But

before the smut appears on the surface, its mycelium grows more or less throughout the corn plant. Every part of the host may be infested by the mycelium, which grows wholly by means of food material derived from the host. In addition to this food tax levied upon the host by the parasite, the corn grains and tassels are often occupied and eventually destroyed by the smut. Finally the spores may fall to the ground and, after a period of dormancy, germinate and produce a short hypha, which bears spores that may serve to infect the next crop of corn with the parasite.[1]

241. Oat smut. The behavior of this parasitic plant (*Ustilago avenae*) (fig. 197) is similar to that of corn smut. The ripened spores may lie upon the ground, adhere to the grains, or remain upon the straw until there are favorable conditions for growth. Probably the grain used for seed is one of the chief means of spore distribution. It has been found that by treating seed oats for a brief period with hot water (132° to 133° F.) or with water containing $\frac{4}{10}$ per cent formalin the smut may be killed.

It is possible for both corn and oats to mature grain even while infected with smut, but usually partial or total destruction of the grains results. Some kinds of corn and oats seem to be more resistant than others to attacks from the disease. The importance of preventing the growth of smut by treatment of seed oats and corn and by a search for resistant varieties of oats and corn is evident.

242. The rust fungi. The rusts are among the most widely distributed and most destructive plant parasites. Many kinds of plants are susceptible to attacks from rusts. Indeed, a given kind of rust may live for a time upon one kind of host plant and later upon another kind. In each stage the rust presents a different appearance; because of this, in earlier studies

[1] "Corn Smut," Ind. Agr. Exp. Sta., 1900.

"The Smut of Grain Crops," *Bulletin 122*, Minn. Agr. Exp. Sta., 1911.

"The Smuts of Wheat, Oats, Barley, and Corn," *Farmers' Bulletin 507*, U.S. Dept. Agr., 1912.

of these plants the different stages were thought to be different plants, and were so named. For example, the rust that develops on leaves of the apple tree early in the spring forms spores. These spores produce the parasite known as cedar apple (*Gymnosporangium*), which grows upon cedar trees. Each stage produces spores which, after germinating in favorable places, produce the other stage of the rust.[1]

Wheat and oat rust is probably the best-known and most-feared member of the rust sub-division of fungi. In the United States it does damage to our wheat and oat crops every year to the amount of at least $15,000,000, and probably much more.

The first conspicuous appearance of rust in the late spring or early summer is in the form of reddish-brown patches upon stalks and leaves of wheat and oats (fig. 198). The patches are composed of large numbers of summer spores (*uredospores*). A section cut through the host leaf enables one to see that the summer spores (fig. 198, *B*) are formed upon the ends of hyphæ. The spore-bearing ends of hyphæ are continuations of hyphæ which have pushed their way among the leaf cells from which they have absorbed their nourishment. At the time summer spores are formed, the host plant is usually thoroughly infested with the mycelium. The summer spores are readily carried about by currents of air or by contact with animals. If placed upon wheat or oat plants, these spores germinate (fig. 198, *C*) and the young hyphæ penetrate the host and produce new mycelium.

Later in the summer the same mycelium which produced summer spores produces a heavy-walled, two-celled spore (fig. 198, *D*) known as the winter spore (*teleutospore*). When formed in large quantities, these spores appear as blistery patches much like those made by the reddish summer spores, except for the difference in color. The winter spores are scattered over the ground and upon wheat and oat straw. After

[1] "The Cedar-Apple Fungi and Apple Rust in Iowa," *Bulletin 84*, Iowa Agr. Exp. Sta., 1905.

"The Asparagus Rust: its Treatment and Natural Enemies," *Bulletin 129*, N. J. Agr. Exp. Sta., 1898.

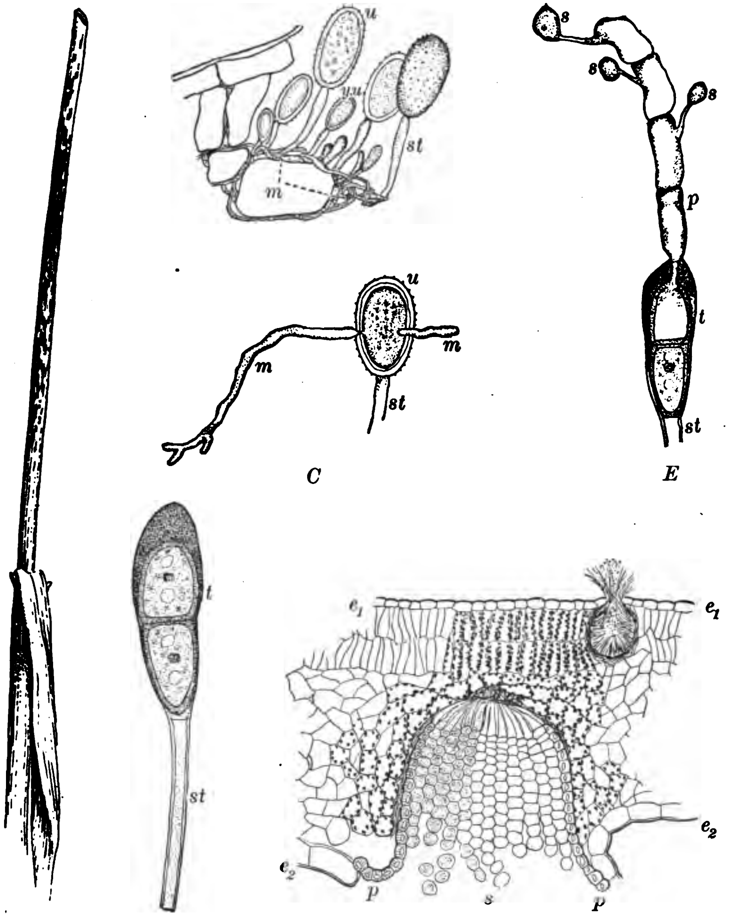


FIG. 198. Wheat rust (*Puccinia graminis*)

A, part of a wheat plant showing rust spots on the stalk. *B*, a small section of a wheat leaf upon which the parasitic rust is growing: *m*, mycelial hyphæ of the rust; *y.u*, young summer spore, or uredospore; *u*, fully formed uredospore; *st*, upright hypha upon which uredospore is formed. *C*, germination of uredospore: *st*, old hypha; *u*, old uredospore wall; *m*, new mycelial hyphæ. *D*, winter spore, or teleutospore: *st*, hypha; *t*, two-celled spore. *E*, germination of teleutospore (*t*): *st*, old hypha; *p*, new hypha, or the promycelium; *s*, spores, or sporidia. *F*, section of the barberry leaf, showing æcidiospore stage of rust: e_1 upper epidermis, and e_2 lower epidermis; *p*, wall of cup, or æcidium; *s*, æcidiospores. All much enlarged. Rearranged from Duggar's "Fungous Diseases of Plants"

a period of dormancy, usually lasting through the winter, these spores germinate. From each cell of the winter spores in the spring there grows a small hypha (fig. 198, *E*). Each cell of this hypha forms one thin-walled spore (*sporidium*).

This rust (*Puccinia graminis*) has another stage in its life cycle. The sporidia, when alighting upon leaves of a shrubby plant known as the barberry, grows and produces within the leaf an extensive growth of mycelium. When this mycelium produces spores, they appear in a peculiar cup on the underside of the barberry leaf (fig. 198, *F*). These spores, being different from any of the three described, and being formed in a cup, are called *cup spores*. Cup spores reproduce the rust plant upon wheat and oats. Summer spores persist through the winter, and it is thought that they also reproduce the rust upon oats and wheat in the following spring. No satisfactory preventive for this fungus has been discovered. Some progress has been made by learning which varieties of wheat and oats are most resistant to attacks by the parasite.[1]

243. Mushrooms. In this sub-division of stalk fungi those members that are good to eat have been popularly called mushrooms, while those not edible were called toadstools. Scientifically there is no accepted distinction of any kind, and the name *mushroom* is now being used for the whole group. In a given genus some species may be edible, others not. Also, some species are edible while young, but not so when older. Some of the more common edible species are easily learned and not readily confused with poisonous forms. In the United States over one thousand edible forms are known, but some of them are very rare.

244. The general character of mushrooms. The mycelium of mushrooms lives entirely within the material which furnishes its nourishment, and from this mycelium it may send up into the air the spore-bearing structure commonly regarded as the entire mushroom. The mycelium becomes very extensive and forms moldy or cobweb-like threads within the rich

[1] "Rusts of Cereals," *Bulletin 109*, S.Dak. Agr. Exp. Sta., 1908.

earth, decaying wood (fig. 183), or other nourishing material.[1] In its growth the mycelium helps to effect decay, and may thereby enrich soils, or, in the case of mushrooms that grow upon living trees, it may hasten their destruction. At times aggregations of the mycelium are formed; these are whitish, bud-like growths (called buttons), which are the beginnings of the

FIG. 199. The "shaggy mane" mushroom (*Coprinus comatus*)

At the left of the main group is one young mushroom just emerging from the soil. The tallest plant in the photograph was 9½ inches high. From A. H. R. Buller's "Researches on Fungi"

mushrooms. They grow and push their way to the surface. As the button elongates, its top begins to expand into the umbrella-like form, and finally opens out as the crown, or pileus, with its center attached to the upper end of the stalk (*stipe*) (figs. 199 and 200). As the pileus opens, it is joined

[1] "The Principles of Mushroom Growing and Spawn Making," *Bulletin 85*, Bureau of Plant Industry, U.S. Dept. Agr., 1905. The United States Department of Agriculture publishes several bulletins upon poisonous and edible fungi.

to the stalk beneath by means of a layer of hyphæ (the *veil*). In some species, when the veil breaks away from the pileus, it forms a ring, or *annulus*, about the stalk.

The underside of the pileus is made up of plate-like growths (*gills*) which radiate from the stalk. Some of the hyphæ which compose the gills extend from the surface of the gill,

FIG. 200. A poisonous fungus (*Amanita muscaria*)

From A. H. R. Buller's "Researches on Fungi"

and upon this extended tip (the basidium, or stalk) four (rarely two) branches are formed. Upon the tip of each branch a spore (*basidiospore*) is formed (fig. 201). When the spores fall upon moist, warm, nutrient material, they produce a new mycelium. If the pileus of a ripe mushroom is cut from the stalk and placed, with the gills downward, upon a piece of ordinary white or blank paper, after a few hours a spore print composed of thousands of spores will be made.

245. Different forms and habits of mushrooms. While the types of mushrooms already discussed and shown in the illustrations are probably most common of all, others are almost equally abundant. A common form is *Polyporus* (many pores) (fig. 182), which appears in shelf-like outgrowths from bodies of trees within which its mycelium grows. It is commonly

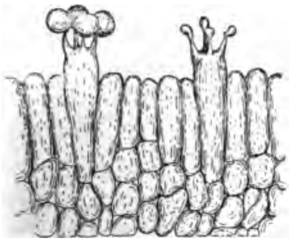


FIG. 201. Basidia and spores of a mushroom

Magnified 370 diameters. After A. H. R. Buller

spoken of as one of the tree-destroying fungi. The mycelium is able to penetrate through woody tissues and to extend for great distances within the host plant. It may infect a living tree when a broken limb or other injury offers an entrance, live within it during the life of the tree, and thereafter help to bring about the decay of the tree. The shelf-like reproductive portion, instead of bearing gills on the under surface, has many small pores within which spores are formed. The number of these spores is very great; one authority[1] estimates

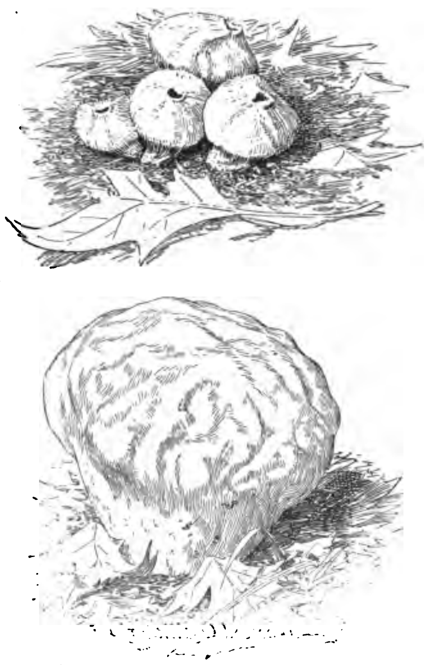


FIG. 202. Puffballs

Two species of puffballs of the genus *Lycoperdon*. Those above are one half natural size; that below is two ninths natural size

[1] Buller, A. H. R., Researches on Fungi. Longmans, Green & Co., 1909.

that a single plant (*Polyporus squamosus*) may produce as many as 11,000,000 spores. The same authority states that one "shaggy mane" (*Coprinus comatus*) mushroom may produce 5,000,000,000 spores. It is obvious that only a small number of these spores succeed in producing new plants; otherwise they would very soon occupy the earth.

246. Puffballs. One of the most important differences between puffballs (fig. 202) and mushrooms is that puffballs produce their spores within an inclosed reproductive body instead of upon gills or within pores. Puffballs may become quite large, even a foot in diameter, and, when ripe, may continue to emit small clouds of spores intermittently for several years. One giant puffball (*Lycoperdon giganteum*) was estimated [1] to contain 7,000,000,000,000 spores.

247. Classification of the thallophytes. The following is the classification of the thallophytes, including the chief genera that we have considered. This classification is placed here for use as a general summary, and not primarily to be committed to memory. If studied carefully, it will give a good review of the three chapters on the groups of thallophytes.

GROUP A. THALLOPHYTES. Since the bacteria and the blue-green algæ are so much alike in structure and in methods of reproduction, they are classified together rather than with the fungi and algæ respectively.

- CLASS I. SCHIZOPHYTES (the fission plants)
  - SUB-CLASS I. SCHIZOMYCETES (bacteria, or fission fungi). Illustrated by numerous type forms and various methods of living
  - SUB-CLASS II. SCHIZOPHYCEÆ, or Cyanophyceæ (the blue-green algæ, or the fission algæ). Leading genera used as illustrations — *Nostoc, Oscillatoria*
- CLASS II. ALGÆ
  - SUB-CLASS I. CHLOROPHYCEÆ (the green algæ). Leading genera used as illustrations — *Pleurococcus, Spirogyra, Cladophora, Vaucheria, Chara*
  - SUB-CLASS II. PHÆOPHYCEÆ (the brown algæ). Leading genera used as illustrations — *Fucus, Sargassum*
  - SUB-CLASS III. RHODOPHYCEÆ (the red algæ). Leading genus used as illustration — *Dasya*

[1] ...r, A. H. R., Researches on Fungi. Longmans, Green & Co., 1909.

CLASS III. FUNGI

SUB-CLASS I. PHYCOMYCETES (the algæ-fungi). Leading genera used as illustrations — *Rhizopus* (bread mold), *Plasmopara* (grape downy mildew), *Phytophthora* (potato blight)

SUB-CLASS II. ASCOMYCETES (the sac fungi). Leading genera used as illustrations — *Sclerotinia* (brown rot), *Miscrosphaera* (lilac mildew), *Morchella* (morel), *Penicillium* (blue mold), *Saccharomyces* (yeast)

SUB-CLASS III. LICHENS. Leading genera used as illustrations — *Parmelia, Usnea* (bearded moss), *Cladonia*

SUB-CLASS IV. BASIDIOMYCETES (the basidium fungi). Leading genera used as illustrations — *Ustilago* (smut), *Puccinia* (rust), *Coprinus* and *Polyporus* (mushrooms), *Lycoperdon* (puffball)

PROBLEMS

1. Why does bread "mold"? How can it be prevented from doing so?

2. Why is it that a plant disease newly introduced into a country seems to spread more rapidly and to prove more destructive than diseases that have long been in that country?

3. Can you account for the fact that lilac bushes seem to be fairly thrifty even though they are infested with lilac mildew?

4. Why are lichens sometimes called "the advance guard of vegetation"?

5. If you can secure the data from published reports, or can perform an experiment for the purpose, determine the difference in yield that may be made by selecting or treating seed oats or corn so as to remove the smut disease. What percentage of gain on the crop may be made in this way?

6. Under what circumstances may fungi that are parasitic upon plants or animals be of service to the farmer or gardener?

7. Why are railroad ties and other timbers often treated with poisonous solutions before they are used?

8. Discover from first-hand study or from publications the life history of some of the worst fungous parasites of your locality.

CHAPTER XVII

MOSSES, LIVERWORTS, AND FERNS

248. Introductory. The mosses belong to the second great division of the plant kingdom, the *bryophytes*, which means "moss plants." All small, green plants are commonly called mosses, but when we discover what kinds of plants mosses are, we shall see how incorrect such a general use of the term is. The bryophytes also include another group, the liverworts, which are peculiar and infrequently noticed plants. The mosses, on the contrary, are extremely abundant and grow in almost all kinds of places. The ferns (*pteridophytes*, which means "feather plants," or "fern plants") constitute the third great division of the plant kingdom and will be considered after the bryophytes. It is so much easier to get clear notions of the bryophytes by a study of the mosses, that we shall give our chief consideration to them, rather than to the liverworts, which are simpler in some ways but less common and less easily studied than mosses.

249. The moss plant. Careful observation of any common moss will enable one to see that it has green, leaf-like structures arranged around a very small stem. Sometimes also there appears upon this leafy stem a slender stalk with a swollen, pod-like tip, or capsule (fig. 203, *C*). In this tip many simple asexual spores are formed, and if we follow the life round of the moss, beginning with the development of one of these spores, we shall get a good notion of the nature of the structures of the moss plant.

Upon the germination of the asexual spore there grows from it a filament, or thread, which looks so much like the algæ that it is often extremely difficult to distinguish it from them.

Its cells contain chloroplasts and can manufacture their own food. Since this filament precedes the leafy moss plant, it is called the *protonema*, which means "first thread" (fig. 203, *A*).

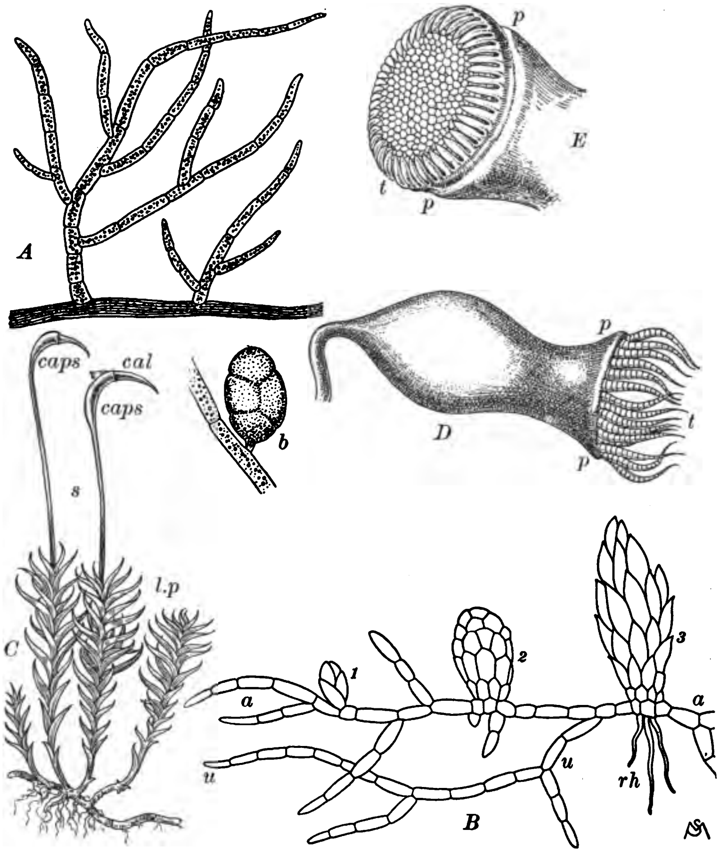


FIG. 203. The life cycle of a moss plant

A, branching protonema, magnified 50 diameters. *B* and *b*, protonema producing buds (1, 2, and 3), rhizoids (*rh*), and underground branches (*u*); magnified 40 diameters. *C*, adult leafy plants (*l.p*), upon which are the sporophytes (*s*) with their capsules (*caps*), in which spores are borne, the capsule tip being covered by the hood, or calyptra (*cal*); natural size. *D* and *E*, enlarged capsules with the mouth, or peristome (*p*), from which the teeth (*t*) extend; magnified 25 diameters. All are the moss *Atrichum undulatum* except *D*, which is *Fissidens adiantoides*. *A* and *B* from Bonnier and Sablon; *C*, *D*, and *E* from Braithwaite

In moist and shady places protonema may grow until great mats are formed upon the soil, old logs, etc., and in these places the alga-like protonema may live for several years.

At times some of the protonemal cells produce outgrowths which divide by oblique walls and form buds (fig. 203, *B* and *b*). The buds may become dormant and lie for months or even longer, and then continue to grow; or there may be no resting period. When they grow, the outermost cells produce leaves, the central ones become the stem, and from the lower ones the root-like hairs (rhizoids) grow. The rhizoids descend into the soil or other substance below the plant, and the leaves and stem rise into the air. The buds, therefore, which grow from the protonema are the beginnings of the leafy moss plant.

250. Sexual and asexual reproduction in the moss. At the tip of the stem of the leafy plant, more or less inclosed by the leaves, the sex organs of the moss develop. These are of two kinds, and with them there are usually taller sterile filaments, which bear chlorophyll and may serve to protect the sex organs. In some kinds of mosses only one kind of sex organ is borne on a single plant, while in other kinds both are produced on the same plant at the same time. Neither can be studied without magnification, although the male sex organs may sometimes be detected without a lens.

The *archegonium*, the female sex organ, is similar in function to the oögonium in *Vaucheria*. It is flask-like and has an elongated neck (fig. 204, *D*). In the swollen part of the archegonium the egg is formed. When the egg is mature, the central cells of the neck become gelatinous, and the end of the neck opens so that there is a passageway through the neck down to the egg. The male sex organ, the *antheridium*, is club-shaped (fig. 204, *A*), being attached by its smaller end to the tip of the plant stem. When the antheridium opens, its thousands of sperms are set free. The sperms swim with great activity, and some of them may come into the vicinity of the neck of the archegonium. One or more make their way down through the gelatinous neck of the archegonium to the

egg, where one of them unites with the egg, thus producing an oöspore, or sex spore.

The oöspore does not have a resting period, as in *Vaucheria*, but begins its growth almost immediately when formed. It enlarges, divides into many cells (that is, it grows), and soon elongates into a stalk one end of which is attached to the old

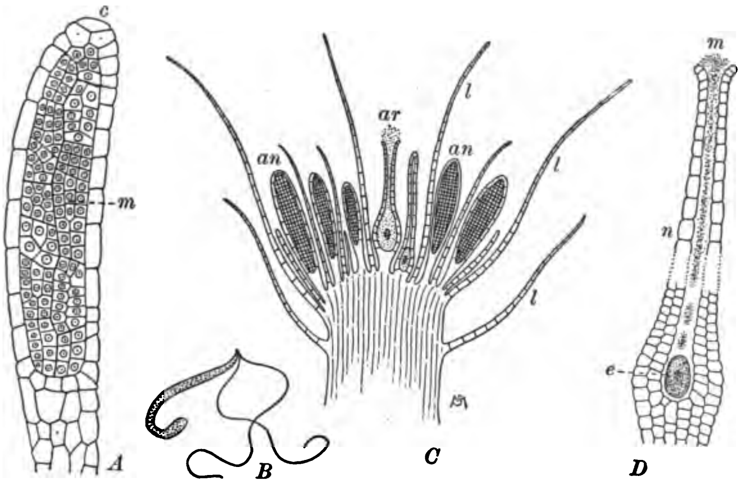


FIG. 204. Reproductive organs of moss

A, an antheridium containing the mother cells (*m*) of the sperms; the cap (*c*) later opens to allow exit of sperm mother cells; *B*, one sperm; *C*, a diagram showing the relations of antheridia (*an*) and archegonia (*ar*), and the leaves (*l*) on the tip of the shoot; *D*, an archegonium with the egg (*e*), the neck (*n*), and the mucilaginous mass (*m*) through which the sperms pass to reach the egg. All are the moss *Atrichum undulatum*. From Bonnier and Sablon

leafy stalk, and the other extends up above the leaves. The stalk which grows from the oöspore bears chlorophyll. A capsule is produced at the tip of this new stalk, and spores are formed by the division of part of the inner tissues of the capsule. Since these spores are formed by division of tissues and not by union of cells, it is obvious that they are asexual spores. When they fall to the ground, they produce protonema again, and thus begin another life round of the moss plant. The

capsule in which the asexual spores are formed is a complex structure. The stalk upon which it is borne is known as the *seta*, which means "bristle" or "hair." In the capsule itself the cap which covers the tip is known as the *calyptra*, which means "hood." The calyptra is the old archegonium wall that was carried upward by the developing stalk. Beneath the calyptra is the mouth, or *peristome*, of the capsule, and over the mouth is an easily removed lid, the *operculum*. Beneath this lid peculiar *teeth* (fig. 203, *D* and *E*) surround the mouth, and through these teeth the spores are dropped or thrown as changes in moisture cause the teeth to move in and out. This elaborate arrangement is thought to secure thorough distribution of the asexual spores of the mosses.

251. Alternate stages in the life of the mosses. It is evident that in the mosses sexual and asexual reproduction are limited to distinct parts of the plant. A moss spore, when it germinates, produces not the part of the plant from which the spore grew, but the other part. Asexual spores germinate and produce protonema, from which the leafy shoot grows by means of buds; the sex spore, or oöspore, germinates and produces the leafless stalk, upon which grows the capsule in which asexual spores are formed. It is customary to speak of that part of a plant which produces the asexual spores as the *sporophyte* (spore plant), and of the part that produces the sex spore as the *gametophyte* (gamete plant), or the part of the plant which produces the sex cells. The sporophyte is therefore the asexual generation of the moss, and the gametophyte the sexual generation, and they alternate in completing the life round of the whole plant. This relation of the two phases is spoken of as the alternation of generations. The fact that the protonema and the leafy shoot are distinct structures does not make a third phase in the alternation, for the reason that there is no spore intervening between them. Also, the term *alternation*, as used, refers only to sexual and asexual generations, and not to cases such as that of the wheat rust, where the asexual phase appears in several different forms.

252. The nutrition of mosses. The stem-and-leaf arrangement of the mosses exposes chlorophyll to the light in a different way from that which was found in the algæ. With the leaves arranged radially about the stem much more chlorophyll is exposed than could be exposed in the same space by a prostrate plant. The importance of the stem in holding these leaves up into the air, thus making the radial arrangement possible, is great. The expanded portions of the leaves are a single layer of cells in thickness, while the median portion may consist of several layers. Moss plants are often favorably placed for securing moisture when moisture is abundant. The whole dense growth made by the hundreds of plants that grow together may act as a sponge in absorbing and holding water, so that at times, when one is walking through mosses, water runs in streams from those upon which he steps. Certain mosses live part or all of the time directly in the water. On the other hand, when long exposed to drying influences, some mosses become so dry that they readily crumble; but if not disturbed, they proceed to grow whenever there is a return of adequate moisture. Mosses may also withstand great extremes of heat and cold.

FIG. 205. A peat-bog moss (*Sphagnum*)

About natural size

253. Peat-bog moss. There are many different kinds of mosses, and they are found in almost all kinds of places where any plants grow. Peat-bog moss (*Sphagnum*) (fig. 205) is a very striking form which, with other plants, often forms peat.

It may grow about the edge of the water or upon extremely wet soil that has been formed by the partial decay of plants. On account of the peculiar structure of the leaves these plants hold water in great quantities. The leafy shoot of *Sphagnum* continues its growth at the tip from year to year, while the older submerged portions gradually become partially decayed and intermingled with other plant material. A semi-solid surface of soil is gradually formed, and this often supports many kinds of plants beside *Sphagnum.* After long periods of accumulation the partially decayed material becomes compressed by the increasing weight above it and is known as peat. When removed and dried (sometimes compressed into bricks), it is used as fuel and finds a market in many parts of the world. *Sphagnum* is quite commonly used as a packing material and also for holding moisture about potted plants.

254. General characteristics of the liverworts. These peculiar plants (fig. 206) take their name from their supposed resemblance to the human liver. Most of them grow in moist, well-shaded regions, though sometimes they are quite exposed and in a few cases they may even grow in intense light and heat. Few of them look much like mosses, but some have leaf-like structures which quite closely resemble them.

The most commonly found liverworts lie flat upon the ground or upon whatever supports them. From the undersurface many rhizoids grow. The plants are usually dark green, being abundantly supplied with chlorophyll. They grow forward, the lobes continuing to branch until solid mats are formed. Older portions of the plant die, leaving the younger branches as new and independent plants.

In some liverworts, cups form on the upper surface, and in these cups small, flattish, green buds are developed. These buds, when they fall from the cups or are removed in some other way, may grow into new liverwort plants. Also, in such liverworts as those shown on page 269, upright stalks grow from the prostrate parts of the plants, and in the heads that are produced on the ends of these stalks the sex organs are

formed. Special antheridial heads produce antheridia and sperms, and special archegonial heads produce archegonia and eggs. The sperm unites with the egg within the archegonium on the underside of the archegonial head, thus forming the oöspore. The oöspore grows and produces an inconspicuous sporophyte, which in turn produces asexual spores.[1]

255. General facts about ferns. The third great division of the plant kingdom is usually spoken of as the ferns (*pteridophytes*). The group includes other classes, two of which are

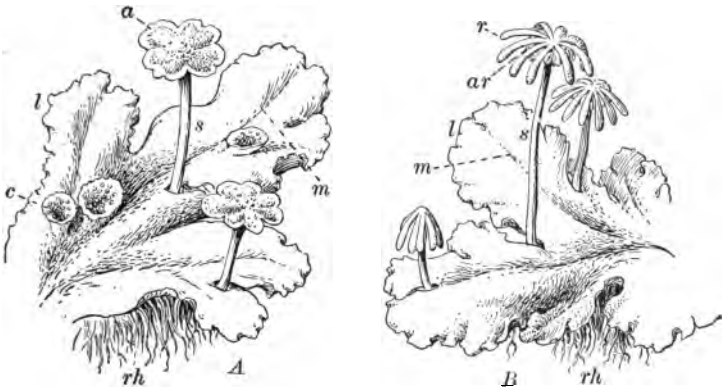


FIG. 206. A common liverwort (*Marchantia*)

A, an antheridial plant; *B*, an archegonial plant; rhizoids (*rh*) and midrib (*m*) of the leaf-like flattened body (*l*); capsules (*c*), in which vegetative reproductive buds are formed; the upright stalks (*s*) are antheridial (*a*) and archegonial (*ar*), the latter being distinguished by peculiar rays (*r*). Slightly more than natural size

the scouring rushes, or horsetails, and the club mosses. There is good evidence that ferns were formerly more numerous upon the earth than they now are, and some of the early ferns were of much larger size than those that now exist. During the times when coal was being formed most abundantly, ferns and their near relatives composed a conspicuous part of the flora. Some

[1] Discussion of the different kinds of liverworts and the details of liverwort reproduction are not important for most elementary classes. In special cases where it is deemed best to make further study, see Bergen and Davis, Principles of Botany.

of these ancient plants doubtless represented classes that are extinct, and others were the older members or the ancestors of the classes which we now have, which in some cases are represented by only a few kinds of living plants.

Most ferns grow in moist regions, but some species are found in peculiarly dry situations, even growing like lichens on nearly

FIG. 207. A group of maidenhair ferns
Photograph by W. H. P. Huber

bare rocks. Although they show considerable variation in form, they can in nearly all cases be distinguished from other plants by their greatly divided, feather-like leaves (fig. 207). Ferns have great range in size, from very small, lowly plants to those as high as a man's head, and to the tropical tree ferns that may be forty feet or more in height. They may occur singly or in thickets so dense as to make it difficult to penetrate them. In all except the tree ferns the parts of the plant that we see are the leaves; the stems and the roots are underground.

256. The rootstock of a fern. If the soil is carefully removed from the underground part of one of the common ferns, the horizontal rootstock (*rhizome*) appears (fig. 208). The lower side of the rhizome gives rise to the roots, and the upper side bears the leaves. At the tip of the rootstock is the bud, by means of which growth is continued from year to year. The leaf scars, or the bases of old leaves, may usually be seen upon the rootstock. The terminal bud grows forward each year from a fraction of an inch in some ferns to several inches in others, and at the beginning of each season it sends up one or more new leaves.

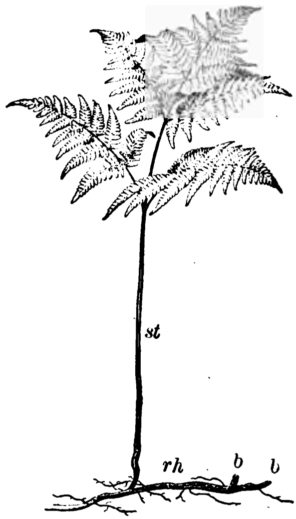


FIG. 208. The bracken fern (*Pteris aquilina*)

The rootstock (*rh*) is horizontal and grows underground; upon it are the buds (*b*) and the upright leafstalk (*st*)

The rhizome of the fern (fig. 209) presents the first really complex stem structure that we find as we study the groups of plants in the order of their increasing complexity. This is a woody stem composed of several kinds of stem tissues. Some of these tissues are heavy-walled and give rigidity to the stem. The rhizome is sometimes stored full of food in the form of starch. Some of the tissues consist chiefly of rounded, fiber-like bundles which extend lengthwise throughout the stem. These are the *fibrovascular bundles*, which term simply means "fibrous bundles of vessels."

257. The leaf of a fern. As a fern leaf develops from the bud, it unfolds in a very peculiar fashion (fig. 211) known as *circinate vernation*. The coiled or rolled (circinate) tip of the leaf is easily seen even in most old fern leaves. Mature fern leaves assume so great a variety of forms that it is impossible to give any description that holds good for many kinds,

and no such description is here attempted. In all leaves the fibrovascular bundles extend throughout the leafstalk into the leaves, where they are known as the veins of the leaf.

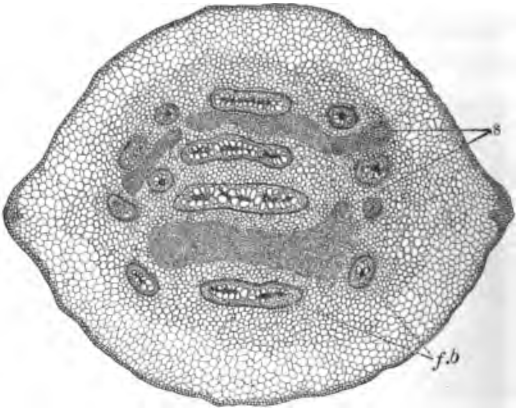


FIG. 209. The rootstock of a fern

The outer part of the stem is made up of hard tissue, and in the interior are also bundles of hard tissue (*s*) known as sclerenchyma; numerous woody bundles (*f.b*) are also surrounded by the large amount of pith

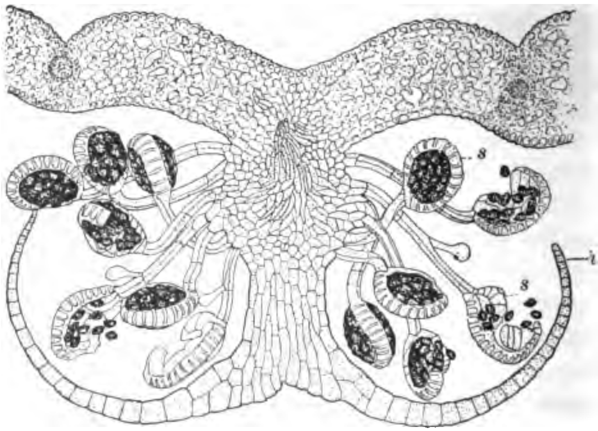


FIG. 210. Diagram of cross section of a fern leaf

On the underside of the leaf are the indusium (*i*) and the sporangia (*s*); within the sporangia are the spores. After Engler and Prantl

The epidermis of the leaf is quite different from anything seen in the liverworts or mosses. When examined with the microscope, it is seen to consist of a single layer of cells, whose irregular walls fit into one another quite closely. In the lower epidermis, rarely in the upper, are the stomata (sect. 33). In a transverse section of the leaf (fig. 210) the other leaf tissues are seen. They are the veins (which appear

FIG. 211. Opening (vernation) of the leaves of Clayton's fern

A skunk-cabbage plant stands in front of the ferns

in cross section as bundles of very small, heavy-walled cells), the chlorophyll-bearing cells, and the sporangia. Between the chlorophyll-bearing cells there are many air spaces.

258. Fern sporangia. On the undersides of most fern leaves the sporangia appear from time to time (fig. 210). An entire group of sporangia is called a *sorus*. The sorus is usually partially or entirely covered by an outgrowth of the leaf known as the *indusium*. The position of the sori (plural of *sorus*) and the nature of the indusium vary widely in different ferns

(fig. 215). Within the sporangium (fig. 210) many heavy-walled asexual spores are produced. In most of the common ferns the sporangia are of the form shown in figure 210. There is a heavy ring of cells which extends over the wall of the sporangium. When ripe these cells become dry, straighten out, and tear the sporangium open; the ring of cells then springs forcibly back to its former position, and in doing so scatters the spores.

259. Sexual reproduction of a fern. The asexual fern spore germinates upon moist earth, pots in greenhouses, etc. It soon grows into a broad, flat, heart-shaped plant (fig. 212) not at all like the fern plant that we ordinarily see. This plant is one layer of cells in thickness at the margin, but along the midrib a cushion of several layers of cells is formed. From the underside and near the base many rhizoids grow. The presence of chlorophyll and contact with moist surfaces aid it in manufacturing its own food.

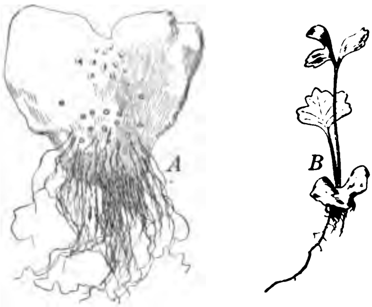


FIG. 212. Gametophyte of a fern

A, the gametophyte (magnified about ten times); *B*, young sporophyte growing from the gametophyte (magnified about three times)

Antheridia may be developed almost anywhere upon the plant before it has become fully heart-shaped, and thereafter they usually develop on the underside, toward the basal region (fig. 212). The antheridium is a globular structure with a single layer of wall cells (fig. 213) and a central region in which usually thirty-two or sixty-four sperms are formed. In size and number of cells this antheridium is much simpler than that seen in the bryophytes. The sperm is, however, quite complex and seems well constructed for swimming.

On the underside of the plant and nearer the tip region are the archegonia (figs. 212 and 214). Only the necks extend outward from the surface, and these usually turn backward,

toward the antheridia. The enlarged part of an archegonium, where the egg is formed, is imbedded. The neck opens, sperms enter, and one of the sperms unites with the egg. The result is the formation of an oöspore, which is inclosed in the tissue. Since this heart-shaped plant produced the sex cells, it is the gamete plant, or gametophyte, and since the asexual spores are formed upon the leafy fern plant, that is the sporophyte. The asexual spore germinates and produces the gametophyte, and the oöspore germinates and produces the leafy

FIG. 213. Fern antheridium, with sperms
Greatly magnified

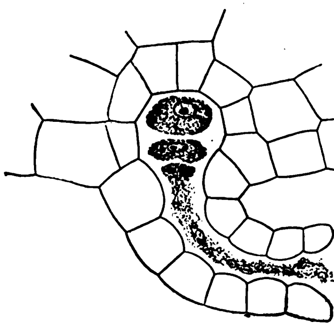


FIG. 214. Archegonium of a fern
Greatly magnified

sporophyte. The young leafy plant at first appears as if it grew directly from the heart-shaped gametophyte (fig. 212). It soon develops leaves and roots and an underground stem — in short, is a new leafy fern plant.

It must be clear that in ferns there is the same kind of alternation between the sexual and asexual generations of the plant as that seen in the mosses, except that in the ferns each stage of the plant lives for a time quite independent of the other stage.

260. Significance of fibrovascular tissue. It is evident that a fern leaf exposes much chlorophyll to the light — much more than does any plant among the bryophytes. The strong supporting and conducting tissues of the leaf uphold the

chlorophyll-containing tissues in such a position that they may receive light; at the same time, through the fibrovascular bundles of the leafstock and the rhizome, soil water and substances in solution may be transported to the chlorophyll tissue. The root system anchors the plant in the earth and absorbs the water needed in food manufacture.

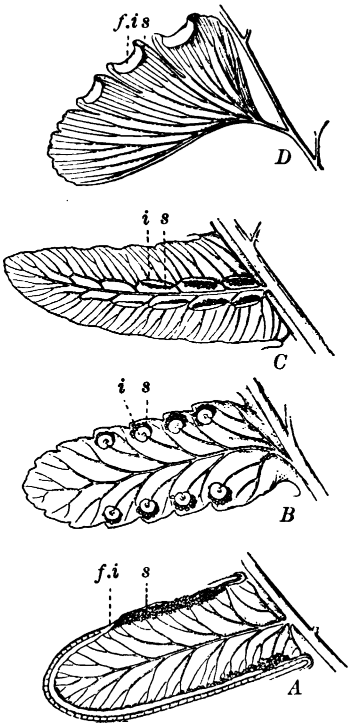


FIG. 215. Types of fern leaflets

A, bracken fern; *B*, shield fern; *C*, spleenwort; *D*, the maidenhair fern. In the different specimens the sporangia are at *s*, the indusium at *i*, and the false indusium at *f.i*

In general, plants that rise above the soil and into the air must be supported and must secure water from some source. The climbing vines which are dependent upon other plants are supported chiefly by these other plants. Most vines procure their supply of water from the soil and transport it by means of their own vascular tissue. Fibrovascular tissue, by reason of its strength, makes possible the upright position and is essential (as is also the absorbing and anchoring root system) alike to the fields of upright grain and to the forests. The importance of vascular tissue in ferns and higher plants can hardly be over-estimated.

261. Types of ferns. Ferns are usually distinguished from one another by the leaves, the sori, and the sporangia. There is much variation in position and arrangement of sori in different ferns (fig. 215). In some the sori are dots placed regularly upon the leaf. In others they are like slits or blistery

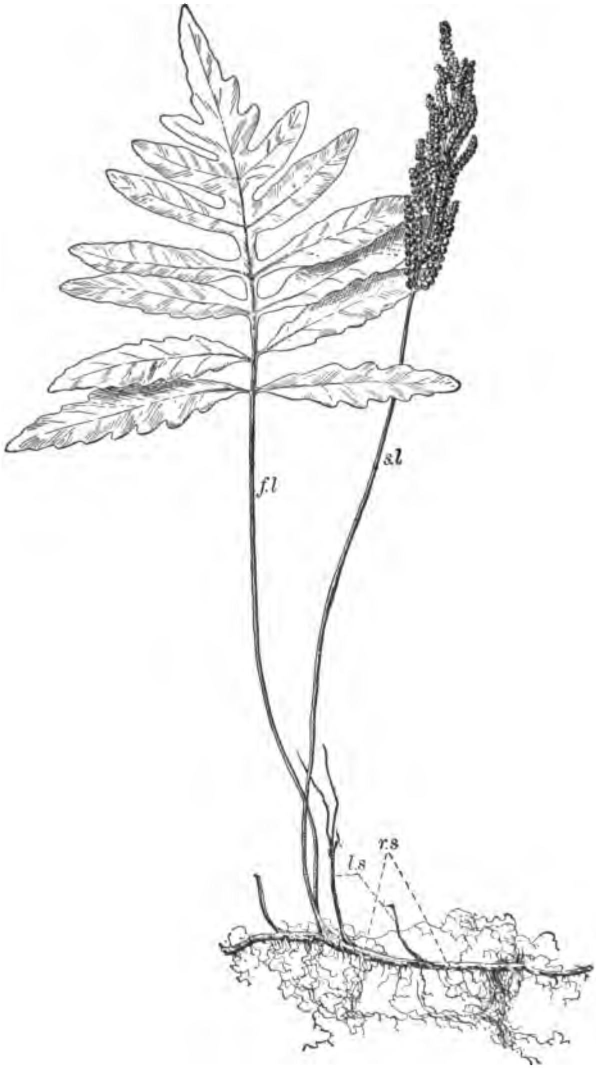


Fig. 216. Sensitive fern, or oak fern (*Onoclea sensibilis*)

r.s, rootstock, or rhizome; *l.s*, leaf bases of former years; *f.l*, foliage leaf; *s.l*, sporangium-bearing leaf. One fourth natural size

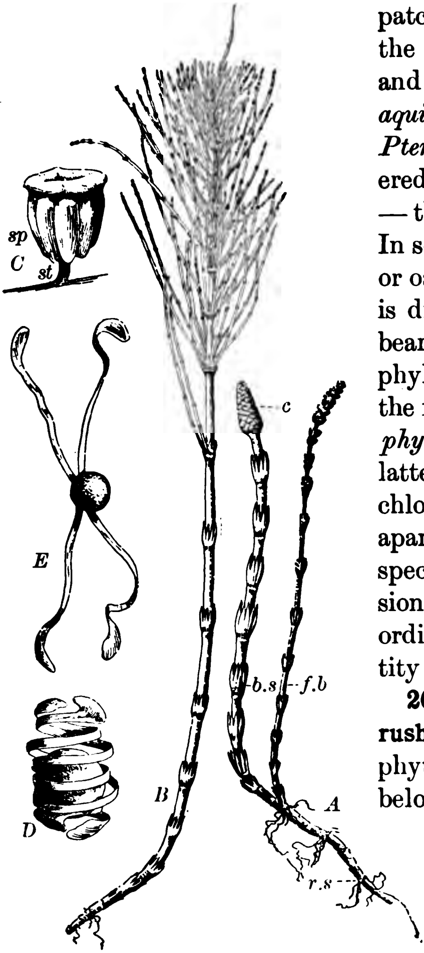


FIG. 217. The common scouring rush, or horsetail (*Equisetum arvense*)

A, a plant in early spring condition; *r.s*, rhizome; *b.s*, spore-bearing branch; *c*, collection of sporophylls (strobilus, or cone); *f.b*, foliage branch, which later expands as in *B*; *C*, one sporophyll from the cone, showing the stalk (*st*) and several sporangia (*sp*). *D* and *E*, spore with elaters. *A* and *B*, one half natural size; *C*, magnified about 20 times; *D* and *E*, greatly enlarged

patches. In still others, as the maidenhair (*Adiantum*) and the bracken fern (*Pteris aquilina*) and other species of *Pteris*, the sporangia are covered by the folded leaf margins — the so-called false indusium. In some, as the sensitive fern, or oak fern (fig. 216), the leaf is differentiated into a spore-bearing branch and a chlorophyll branch. In such cases the former is called the *sporophyll* (spore leaf), and the latter the *foliage* leaf, the chlorophyll bearer. Setting apart special structures for special pieces of work (division of labor), as here shown, ordinarily increases the quantity and quality of work done.

262. Horsetails, or scouring rushes. The class of pteridophytes to which these plants belong once constituted a prominent part of the earth's flora as tree-like plants. They are now represented by the single genus *Equisetum*. Fossil remains tell interesting stories of the ancestors of these plants which lived ages ago when coal was being formed in abundance.

Modern equisetums live about open marshes, in sandy wastes, and along railroad embankments. They have hard, rough, siliceous stems, with small leaves that form sheaths about the joints of the stem (fig. 217). In the most common species of *Equisetum* the sporophyll branch appears very early in the spring and produces at its tip the strobilus, or cone, which bears the sporangia upon greatly reduced and transformed leaves (sporophylls). The bushy chlorophyll branch appears later and is the one which grows throughout the season, the sporophyll branch disappearing as soon as the spores have been shed. The spores are attached to peculiar strap-like outgrowths known as elaters (drivers). The elaters are supposed to assist in distributing the spores.

The bushy foliage, or chlorophyll part of the plant, grows and deposits food material which may be used the next season for the growth of the sporophyll branch.

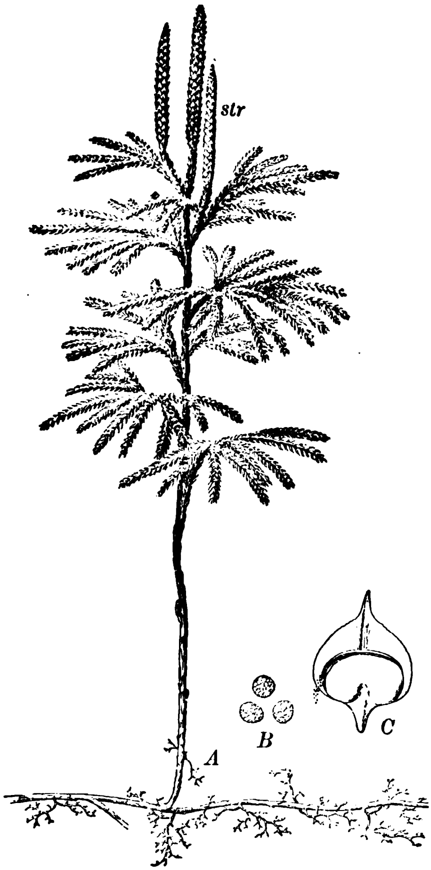


FIG. 218. A club moss (*Lycopodium*)

The horizontal rootstock, with its roots, grows within or upon the humus. The upright branches (*A*) bear green leaves and strobili (*str*) (also called spikes or cones) in which spores are formed. At *C* is shown one leaf from the strobilus, and upon this leaf is a sporangium. From the partially opened sporangium, spores escape. *B* shows enlarged spores

263. Club-mosses, or ground pines. These plants constitute another class of the pteridophytes. The most common ones belong to the genus *Lycopodium* (fig. 218). *Lycopodium* plants are found mostly in the cooler temperate regions. At Christmas time they are shipped and used extensively in decoration throughout the United States. Their stems, which are underground or under leaves, etc., their upright branches and symmetrically arranged leaves, and their prominent spore-bearing cones are striking features of these plants. The collections of sporophylls in these plants and in *Equisetum* are sometimes spoken of as flowers but are more properly called strobili, or cones.

264. Pteridophytes of past ages. The surface of the earth has undergone many sweeping changes since plants first began to live upon it. In some periods of the earth's history conditions favored certain kinds of plants, and these flourished. When less favorable periods came, these once-successful plants were greatly reduced in number, or possibly were eliminated. We have records of what some of these former plants were. These records were made by the plants themselves, for when they died they sometimes became fossilized, or made prints in soft mud or other substances which afterwards hardened. By means of fossils much is being learned about the kinds of plants that used to exist. The ancient fern-like plants were widely distributed over the earth. Certain periods (as the so-called carboniferous period) were peculiarly favorable in temperature and moisture to the growth of pteridophyte types of plants, and they grew to much greater size and in much greater profusion than even our present tree-ferns of the moist tropics. After a long period of growth, when multitudes of the plants had died and fallen, conditions changed and these masses of plant material became submerged and then buried beneath layers of rock and earth, and at length coal was formed from them.

265. Classification. The following classification may assist in keeping leading facts in mind, but it is presented as a means of review rather than as an outline to be committed to memory.

GROUP B. BRYOPHYTES

CLASS I. HEPATICÆ (liverworts). Genus used as illustration — *Marchantia*

CLASS II. MUSCI (mosses). Leading genera used as illustrations — *Atrichum* and *Sphagnum*

GROUP C. PTERIDOPHYTES

CLASS I. FILICINÆ (the true ferns). Leading genera used as illustrations — *Pteris* (the bracken fern), *Adiantum* (the maidenhair fern), *Onoclea* (the sensitive fern, or oak fern)

CLASS II. EQUISETINÆ (horsetails, or scouring rushes). Genus used as illustration — *Equisetum* (the only living genus of the class)

CLASS III. LYCOPODINÆ (club mosses or ground pines). Genus used as illustration — *Lycopodium* (one of the three living genera of the class)

PROBLEMS

1. Of what importance are mosses as soil formers?

2. What is the significance of the radial arrangement of the leaves of the moss plants?

3. Why is it important to the plants that the asexual spores of mosses, liverworts, and ferns should have wide distribution?

4. In what sense is it true that the vascular tissue exemplified in ferns means about the same to the plant kingdom as the vertebral column (backbone) means to the animal kingdom?

5. Why is it that peat-bog moss is good material for covering the soil of potted plants and for packing fragile articles for shipping?

6. In what ways may ferns be propagated vegetatively? How do florists propagate their ferns?

7. What structures of ferns help to explain the fact that most ferns thrive best in damp and shaded regions?

8. In museums that you have visited what fossil evidences are there that ferns lived during former ages?

CHAPTER XVIII

THE SEED PLANTS[1]

266. Introductory. In the earlier chapters of this book we dealt only with flowering or seed plants, which belong to the fourth great division of the plant kingdom. This division is known as the spermatophytes, which means "seed plants." In fact, our earlier discussions considered practically no plants except members of the second of the two groups of seed plants — the angiosperms, or plants with inclosed seeds. The other group of seed plants is the gymnosperms, or plants with exposed seeds. Seed plants are the most conspicuous plants of the earth, and are the ones which people ordinarily regard as composing the plant kingdom. They are most important in agriculture, horticulture, landscape and vegetable gardening, forestry, and the industries. We shall first consider the gymnosperms, of which there are over four hundred species, some widely distributed and some limited to small areas.

267. Gymnosperms — the pine as a type. The pine is the best general illustration of the gymnosperms and is by far the most widely distributed member of the group. Sometimes pines form dense forests of tall, straight trees standing close together. It is only when thus crowded that they grow tall, since, when growing alone in open territory, they secure ample light without attaining such a height.

With a deep-growing central taproot and extensively branched lateral roots the pine plant holds its place in the

[1] This chapter summarizes some of the things said about seed plants in the first chapters of this book, and adds discussions which will enable the student to see in an elementary way the relation of the seed plants to the groups of lower plants discussed in the immediately preceding chapters.

soil and supports the heavy stem and branches. The stem is generally straight, and the branches usually rise in whorls. The lower branches are longest, so that the whole tree presents a cone-like outline (fig. 219). A heavy bark of a kind not seen in any of the lower plants covers the roots, stem, and branches. Leaves are borne only on the younger branches. The small scale leaves are inconspicuous, while the needle leaves are the ones usually observed.

FIG. 219. A white pine (*Pinus Strobus*)
The stem is almost straight, the branches stand approximately at right angles to the stem, and the top is irregularly conical

268. Needle leaves. The needle leaves are borne in pairs (fig. 220), in threes, fives, etc., the number varying with the different species. The number of leaves in a cluster is one of the distinguishing characteristics of the species of pines; for example, the white pine (*Pinus Strobus*) has five leaves in a cluster, the scrub pine (*Pinus divaricata*) and others have two leaves in a cluster, the Georgia long-leaf pine (*Pinus palustris*) has three, and others have a variable number (from two to five) in each cluster.

If one of the clusters of needle leaves is pulled away from the branch that bears it, and its basal scale leaves are removed, there will be seen a very small white branch upon which the

needle leaves grow. The needle leaves are really continuations of these small branches. The inward faces of the leaves are so arranged that all of one cluster, when put together, compose a cylindrical leaf mass. That is, when two leaves compose the cluster, the leaf branch is divided into halves; when three or five are in one cluster, the branch is divided into three or five parts.

FIG. 220. A branch of a pine

At the left is a one-year-old cone (*c*), and at the tip of the shoot (*s*) a very young cone (*yc*) just open and ready to receive pollen. On the young shoot are the young needle leaves, and at the tip is the bud (*b*), which continues the growth of the stem

Gymnosperms are chiefly evergreen (that is, keep their old leaves until after new ones have come), but some of them, as the larch, or tamarack, and the bald cypress, are deciduous (that is, shed their old leaves before the appearance of the new ones). The periods during which the leaves endure, range in different species from two to four years. By determining the age of the branches through a study of the yearly bud scars one may readily ascertain how long the leaves last on any pine tree.

The clusters of pine leaves are arranged spirally around the stem, as may be learned, when they have fallen, by an examination of the leaf scars.

269. Internal structure of needle leaves. The stiffness of pine leaves is one of their most noticeable features, and when we examine a cross section, we are able to locate the tissues that give the leaves their rigidity. The outer layer of cells, the *epidermis* (fig. 221), has an extremely heavy covering, the *cuticle;* beneath the epidermis there are other heavy-walled

cells (the *strengthening cells*). Other parts of the leaf are the *stomata*, which are deeply placed in the epidermis and are often so clogged with dust that they are quite dark in appearance;

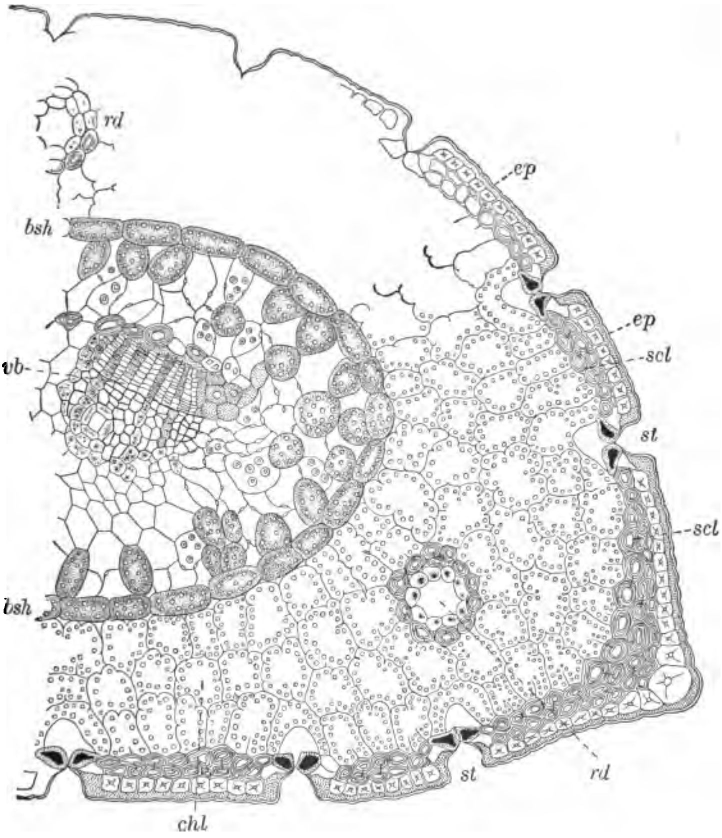


FIG. 221. Part of a cross section of a pine leaf

The epidermis (*ep*), upon which is a layer of cuticle; a layer of heavy-walled cells, or sclerenchyma (*scl*); stomata with deeply placed guard cells (*st*); chlorophyll-bearing tissue (*chl*); resin ducts, or channels (*rd*); bundle sheath (*bsh*), which incloses two vascular bundles (*vb*). Greatly magnified

the *chlorophyll tissue*, through which run the *resin ducts;* the *pith region*, through which run two groups of *fibrovascular bundles*, but one of which is shown in the figure.

The well-protected chlorophyll tissue is able to withstand severe cold and drought, and lives through periods that would kill deciduous leaves. The amount of leaf surface is comparatively small, but pine leaves probably begin their work earlier in the season than deciduous leaves do, and continue their work later.

270. New leaves and branches. When the growth buds open in the spring, the branch extends, the new needle leaves begin to elongate (fig. 220), and within a few weeks the leaves reach their full size. This new growth was started in the preceding summer and autumn, so that within the bud during the winter there were the very small stem and leaves of the next spring's growth. The scales from the growth buds fall away and leave scars, by means of which the former position of the end of the stem may be located. Also, by observing these bud scars from the tip to older portions of the branch, the age of the branch and the rate of elongation may be determined.

271. The branch and stem. From transverse sections of branches and stems of different ages their general structure may be observed.[1] Innermost is a small pith region, which in older stems is compressed until it is not usually noticeable. Around this is the woody tissue (*xylem*) of the fibrovascular bundles. The woody tissues are joined together in such a way as to form a solid woody cylinder. It is possible to determine the age of the twig approximately by counting the layers or rings of wood, except when two or more distinct growth periods occur in the same season. In such cases more than one ring would be formed in the same year. At the outer edge of the woody tissue is a thin layer of cells (*cambium*) which separates the woody tissue (*xylem*) from the outer tissue (*phloëm*). The cambium is actively growing tissue which produces new wood within and new phloëm without. The tissues outside the phloëm which we need to notice are the green bark and the dead bark. Dead bark is constantly being formed from the green bark within. This results in making the dead bark

[1] A hand lens will enable students to observe these regions of the stem.

FIG. 222. A group of "big trees" (*Sequoia gigantea*) in California

These trees grow to great size and height, one famous tree being 268 feet high. Photograph by King

constantly thicker, until finally, in older branches and stems, the light penetrates through it poorly, if at all, and chlorophyll ceases to be developed. The ridging of bark is due to the fact that bark on young branches and stems is so spread by growth within that longitudinal cracks are formed. As more wood is developed within, the spreading and thickening are increased, and ridges and crevices become more pronounced (fig. 222), as is true in most perennial stems.

272. Rate of thickening of the stem. Two of the most important of our gymnosperm trees are the white pine and the long-leaf pine. A white-pine tree overtopping most of its fellows in the forest is, on the average, at ten years 0.9 inch in diameter, at one hundred years 17.2 inches, and at two hundred years 31 inches. The average thickness of the annual rings during the life of the tree throughout its second century is therefore about $\frac{1}{14}$ inch. In the Southern pine the growth is slower. The increase in thickness of a tree two hundred twenty years old and $17\frac{3}{4}$ inches in diameter was only 1 inch during the last forty years, or $\frac{1}{40}$ inch per year.

FIG. 223. Seed cone of Scotch pine (*Pinus sylvestris*) which has opened and dropped its seeds

The tallest and least shaded white-pine trees at fifty years develop new wood at the rate of about $\frac{1}{4}$ cubic foot per year; at seventy-five years at the rate of about 1 cubic foot per year, and at one hundred years at the rate of about $1\frac{1}{2}$ cubic feet per year.[1]

273. Significance of the stem. The gymnosperm stem is more complex than that of any other plant in the series of groups that we have been studying. There was vascular

[1] For further discussion of the rate of growth of pine trees see "The White Pine," *Bulletin 22*, U.S. Dept. Agr., Division of Forestry.

tissue in the ferns, but in the pines and their relatives the vascular tissue is organized into a stem that may attain great height and thickness (fig. 222). These plants have been highly successful in the struggle for light. Such plants also have quite extensive woody root systems, which serve to anchor these great trees and to gather the water and substances in solution that are conducted through the whole length of the stem to the leaves.

The significance of the stems of gymnosperms and some angiosperms to those industries that use timber is difficult to estimate. Timber is used for all sorts of useful and ornamental products, and many kinds of industry are dependent upon timber; but it must be remembered that woody stems are developed as structures which support leaves and conduct food materials to and from them, in connection with the plants' struggle to live, and that man's use of this timber is, botanically, merely incidental.

FIG. 224. Diagram of part of a seed cone of a pine, with ovules in normal position

S, sporophylls, or leaf-like parts of the cone; *O*, ovule; *I*, the covering of the ovule, called the integument; *FG*, the female gametophyte, which bears the archegonium *A*, in which the egg is formed; *Pt*, pollen tubes from pollen grains which lie upon the tip of the ovule

274. Pine cones. Two kinds of cones are borne upon pines: one is the seed-forming cone (fig. 223); the other is the staminate cone. The seed cone is composed of heavy, leaf-like parts, on the upper sides of which the developing seeds or ovules are formed. Within the ovule the egg is produced (fig. 224). The staminate cones appear early in the spring, shed their pollen, and soon wither and fall to the ground. These cones

are made up chiefly of stamens, which bear large pollen sacs (fig. 225) from which pollen is shed in great quantities. It may be carried long distances, and its transportation may be facilitated by peculiar wings, or outgrowths, upon the walls of the pollen grains. Sometimes the pollen is shed in such great abundance that some people have thought it was a shower of sulphur from some distant volcano.[1]

275. Pollination. As was learned in the chapter on pollination and fertilization, the pollen (or microspores) must be placed on the part of the flower which bears the ovules before the pollen grows. It was also learned that the proper placing of the pollen is known as pollination, and considerable study was made of the different ways in which pollination occurs. In the pines the young seed cones stand upright and open (fig. 220) at the time the pollen is being shed. If pollen grains chance to come into the seed cones, they slide down upon the leaf-like parts to the base, where the sporangia are borne. By means of a sticky secretion they are then caused to adhere to the tip of the ovule, and pollination is completed. In order that pollination in pines may be complete, it is evident that the air must be full of pollen when the ovules are ready to receive it; and this is the case. The pollen is not only very abundant but, because of its lightness, is easily transported.

276. Fertilization. In the ferns the egg is borne in the archegonium, the neck of which opens to the exterior, so that the sperm may swim directly into the passageway leading to the egg. In the gymnosperms, on the contrary, the egg is imbedded within the tissue of the ovule. After the pollen grain falls upon the ovule, there grows from its wall a tube

[1] Unfortunately for the learner, each of the structures that compose the staminate cone has had two or more names applied to it, all of which are in use in botanical writings. The pollen grains are also known as *microspores* (small spores); the pollen sacs are called *microsporangia* (small spore sacs); the stamens are called *microsporophylls* (small spore leaves); the whole staminate flower is called the *strobilus*, a name which was used for the cone of the club moss and in a way distinguishes it from the type of flower that is found in the angiosperms.

known as the pollen tube. While the tube is developing, its contents divide and produce several cells, two of which are male cells (fig. 225). The tube makes its way to the egg, and when it arrives, its tip opens and the two male cells pass out.

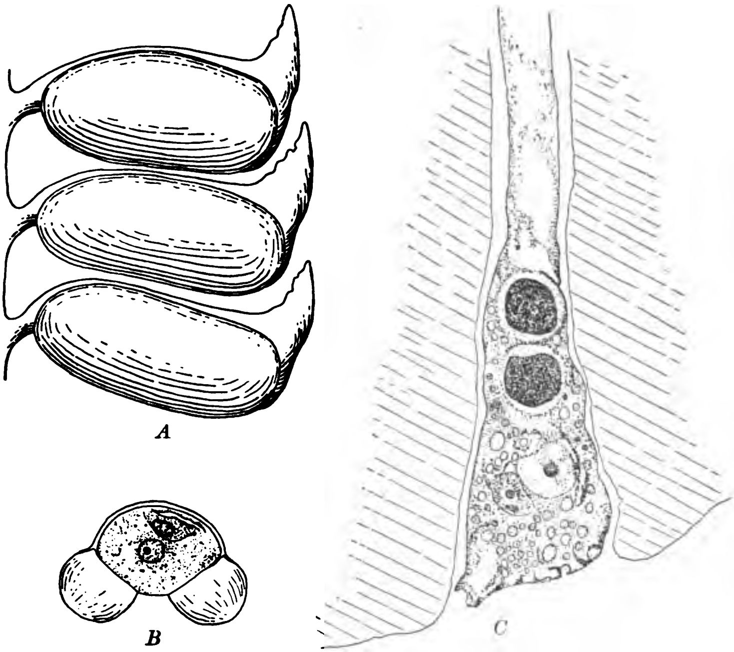


Fig. 225. Stamens, pollen, and pollen tube of the pine

A, a few of the stamens and pollen sacs from a staminate cone; somewhat magnified. *B*, an enlarged pollen grain; much magnified. *C*, the tip of a pollen tube at the time when it has almost reached the egg; just back of the two nourishing cells are the two darkly colored male cells, either of which may fertilize an egg; much magnified

Either of the male cells may unite with the egg to produce an oöspore; the other disappears. These male cells would be called sperms if they had cilia, but they have not. There are a few gymnosperms (the older ones most resembling the ferns) in which the male cells have cilia, can swim actively, and are true sperms, but even these are carried by the pollen tube.

277. Seed formation. The oöspore that is formed by the union of the sperm and the egg grows and becomes the embryo of a new pine plant. The tissues that surround this developing embryo are partly absorbed by it and used in nourishing it. By the time the embryo has developed root tip, stem tip, and young leaves, the walls of the ovule have begun to harden, and the whole structure is recognized as the seed (fig. 226). When the pine cone opens, usually two years or more from the time when pollination occurred, the seeds fall to the ground and, if conditions are favorable, begin to germinate. In germination the embryo swells and bursts the seed coat, the root grows downward into the soil, and the leaves rise into the air; in time the embryo becomes a new tree, which may bear cones and repeat the process of reproduction.

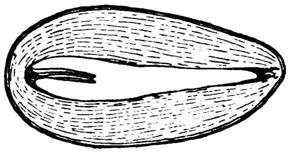


FIG. 226. Diagram of the seed of a pine, showing the embryo (new pine plant) inclosed within the food material

At the right tip of this embryo is the root, and at the left are the seed leaves which inclose the small stem tip

The cones may not shed their seeds for several years (as in the case of the lodgepole pine of the Rocky Mountains), or not even until the death of the tree, and the young plants within the seeds may still remain alive and ready to grow when properly placed for germination. It is becoming a common practice of forestry to collect pine seeds in great quantities and sow them over thousands of acres, thus resetting or extending the areas in which pine seedlings grow.

278. Other gymnosperms. There are several groups of gymnosperms, but the one to which the pines belong (the conifers) is the only one that need be mentioned here. The conifers take their name from the cone-bearing habit which is characteristic of all members of the group. In addition to the widely distributed genus (*Pinus*) already discussed, other important representatives of the conifers are the spruces (*Picea*), which have stubby needle leaves (fig. 227, *A* and *B*), close-set branches, and pendent cones; the Western hemlock, the Douglas fir

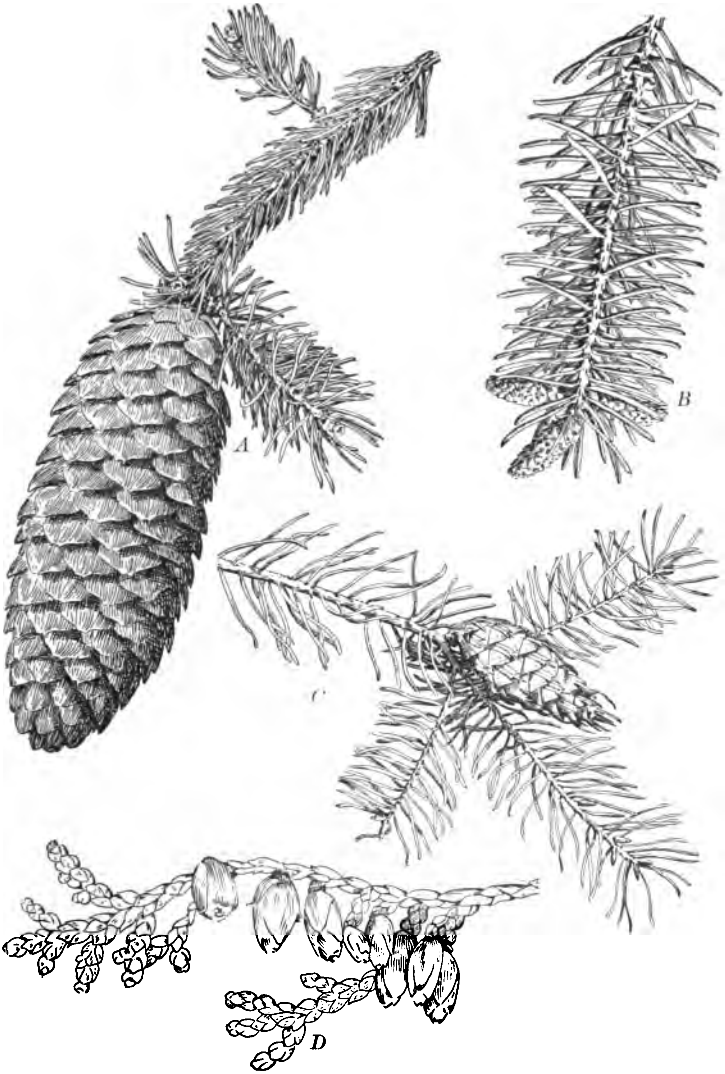


Fig. 227. A group of gymnosperm cones, of which all except *B* are seed cones

***A*, spruce (*Picea excelsa*), one half natural size; *B*, spruce, branch and staminate cones almost natural size; *C*, Douglas fir, or Douglas spruce (*Pseudotsuga taxifolia*), one fourth natural size; *D*, arbor vitæ (*Thuja occidentalis*), almost natural size**

(fig. 227, *C*), and the fir trees (*Abies*); the Southern bald cypress (*Taxodium*), which, with the tamarack (*Larix*) of the Northern bogs, are deciduous conifers; the Northern white cedar, or arbor vitæ (*Thuja*) (fig. 227, *D*), and the Southern white cedar (*Chamaecyparis*); the red cedar, juniper, and low juniper (*Juniperus*); and the redwoods and "big trees" (*Sequoia*) of the western part of North America (fig. 222).

279. Products of gymnosperms. We naturally think of timber as the chief product of gymnosperms. By far the largest part of our primeval forests were of coniferous trees, and these are still much more abundant than all other kinds of trees. The pines and other conifers produce over three fourths of the timber of the United States. The white pine (*Pinus strobus*), the long-leaf pine (*Pinus palustris*) (fig. 229), and the loblolly pine (*Pinus taeda*) of the Southern states, the bull pine (*Pinus ponderosa*) and the sugar pine (fig. 228) of the Pacific coast and the Rocky Mountain region, and the very widely distributed spruce (*Picea*) are used in large quantities.

The western Douglas fir is a timber tree of great size and importance; the bald cypress of the South has produced immense quantities of lumber, though the available supply is becoming limited; the redwoods of the Western coast are important, but the preservation of the redwood forests is limiting their output, since natural-history interests of forests sometimes outweigh their importance as sources of lumber.

In addition to ordinary uses for construction work, railroad ties, and fuel, coniferous woods have many special uses, as the use of red cedar in making lead pencils and moth-proof chests. Several species of nut-bearing pines in western North America and one in southern Europe bear edible seeds which are used as food; valuable extracts, as pine tar, rosin, and oil of turpentine, are obtained in this country and are derived chiefly from the long-leaf pine (fig. 229).

280. Gymnosperms once more abundant. We have already learned that during the carboniferous age the ferns and their relatives were the dominant plants, but fossil remains prove

FIG. 228. Sugar pine bearing the large seed cones

These cones are often over a foot in length. Photograph by King

that seed plants were also present during that time. It was later, during the next age, that gymnosperms became most abundant. There are fossil remains of giant gymnosperms — trees so well preserved that even the nature of the seeds may be determined. In those times gymnosperms were everywhere. The "big trees" and redwoods extended to Greenland, and other groups now well-nigh extinct grew in profusion over very wide areas. Pines did not become abundant until late in the development of gymnosperms, and they are still widely distributed and fairly luxuriant in their growth. No doubt the climate and physical conditions upon the earth have undergone very extensive changes during the earth's history, and in consequence plant life has changed. Therefore the plants now surviving from former abundant groups have probably undergone many alterations since the times when their ancestors were dominant. But they stand as living evidences of the kinds of plants that were most abundant before the last great group became the dominant plants of the earth. That group is the angiosperms.

281. Angiosperms: their diversity. This is the second group of the seed plants and is therefore the highest group of the plant kingdom. Angiosperms exhibit the widest variation in form and in habits of living. As water plants they may be submerged or free-floating, or may grow in water part of the time and on land part of the time; they may grow in regions that are so dry and exposed as to make life seem impossible. They thrive luxuriantly in the tropics, and even live upon the ice in frigid regions. They may live as epiphytes, or as vines climbing upon other plants. They may be parasites, saprophytes, or even carnivorous plants. In form the angiosperms range from diminutive floating disks to gigantic trees. In length of life they range from those that complete their life round many times during one year to individual plants that live to be several centuries old.

The total number of species of angiosperms is not definitely known, but botanists agree that there are over one hundred

FIG. 229. The Southern pitch pine, or long-leaf pine (*Pinus palustris*), which is used as a source of turpentine and pitch

Note the method of tapping the trees to secure the resinous secretion. Photograph by the United States Division of Forestry

thousand species, and some think this number too low. Added to this fact of the large number of species is the fact that the number of individuals of a species may often be enormous, as in the common blue grass, oats, or corn, each species of which consists of unknown millions of individual plants.

The diversity of angiosperms in chemical composition is equally great. Some constitute our most important foods, others produce a large part of our medicines, and others produce substances so poisonous that they are feared by all who know about them.

282. Vegetative structures. The essential facts regarding the ways in which angiosperms make and use their food material have already been given (Chapter II and the following chapters). There have also been abundant discussions to show something of the variety of structures that plants of this group exhibit when they grow under different circumstances, as in the water, on especially dry land, and under extremes of temperature. The ways in which different vegetative structures are used as means of reproduction are presented in chapters on roots, stems, leaves, etc. Reproduction by means of flowers has also received some attention, but a further discussion at this time will serve to connect the angiosperms with the preceding groups.

283. The angiosperm flower. The name *flower* is sometimes used in speaking of the collections of sporophylls that are seen in the cones of pines. In the angiosperms, in addition to sporophylls, there are usually other leaf-like organs around the sporophylls, and the presence of these additional floral leaves is popularly considered as essential to the flower (figs. 9 and 102). These added floral leaves are usually colored, often in very striking ways. There are angiosperm flowers that do not have these added floral leaves, such flowers being naked (fig. 104). No complete distinction can be made between the collection of sporophylls, which in the pines was called a strobilus, and the collection which is commonly known as a flower in the angiosperms.

The essential structures of a flower are *stamens* (*microsporophylls*) and *pistils*, or *carpels* (*megasporophylls*). A carpel, strictly speaking, is one megasporophyll, and when several carpels are united, the result is known as a compound carpel. The name *pistil* is used without discrimination for either a simple or a compound carpel.

The flower and the resulting seed that characterize this group of plants has often led people to give to the angiosperms names which suggest these characters. The most common of these names are *flowering plants* and *seed plants*. The name *phanerogam*, meaning "plants with visible reproduction," was applied when botanists knew less of the intricacies of the reproduction of angiosperms than is now known. In the same way *cryptogam*, which means "plants with hidden reproduction," was applied collectively to the pteridophytes, bryophytes, and thallophytes. These names are still used by many people, but it is evident that an interchange of the names would better fit the facts of reproduction in the groups of the plant kingdom.

284. Stamens and pollen. In connection with the discussion of the gymnosperms the structures of the stamen are fully illustrated (fig. 225). The parts of the angiosperm stamen — the anther and the filament — are similar to the same structures in the gymnosperms, though of course many variations appear. In the young angiosperm anther there are four sporangia, and these, when they ripen their spores, unite in pairs, so that two pollen sacs are formed from the four sporangia (fig. 108). The anthers of the angiosperms may open in a variety of ways, the method of opening being called the *dehiscence*.

Since the pollen grains are formed by the division of cells in a sporangium, it is evident that they are asexual spores. When mature each pollen grain consists of a heavy outer wall, an inner wall, cytoplasm, and nucleus (fig. 118). Often there are starch and oil foods in the pollen grains. The single-celled pollen grain sometimes begins to germinate before it leaves the anther in which it was formed, and when this has

occurred, two cells, and not one, are to be seen within the wall of the pollen grain. The pollen grains must be placed upon the tip of the stigma before further development takes place. The process of proper placing of the pollen grain is known as pollination, to which a chapter has already been given (Chapter X).

285. The pistil. The pistil, or carpel, consists of three parts: the enlarged base, which is called the *ovary*, in which the ovules or developing seeds are borne; the elongated portion above the ovary (the *style*); the tip of the style, usually more or less expanded (the *stigma*). The stigma, when ripe, is ordinarily covered by a sticky fluid which causes the pollen to adhere to it. Through the style the pollen tube grows to the ovules. The ovules may be borne singly or many together in the ovary. They may be attached on the bottom, at the sides, at the top, or on a central axis of the ovary. While the ovules differ so much in their position, there is a general uniformity in their individual structure. The surface of the ovule consists of one or two *integuments*, which at the tip do not quite cover the inner tissue of the ovule. This open tip is the *micropyle*, which means "little gate." Similar structures of the ovules of gymnosperms have already been mentioned (sect. 274). Within the tissue of the ovule is the *embryo sac* (fig. 231). When fully formed the embryo sac incloses seven cells. At the micropylar end of the sac are three cells, the central one of which is the egg, while those at the sides of the egg are the helper cells, or *synergids*. These helper cells may nourish the egg or possibly may assist the development of the entering pollen tube. In the end of the sac opposite the micropyle are the *antipodal* cells, which usually disappear soon after they are formed; and in the central part of the sac is the endosperm cell, which later grows and produces the food or endosperm of the seed.

286. The pollen tube and fertilization. After pollen grains have fallen upon the stigma, the outer wall of the pollen grain breaks, and from the inner wall the beginning of the pollen tube extrudes. The tube tip enters the stigmatic tissue and

forces its way through the central softer tissues of the style. It does not make a passageway by forcing the tissue aside, but by means of its own secretions (*enzymes*) it breaks down these tissues, and they doubtless furnish nourishment to the growing pollen tube (fig. 230). When the tube reaches the cavity

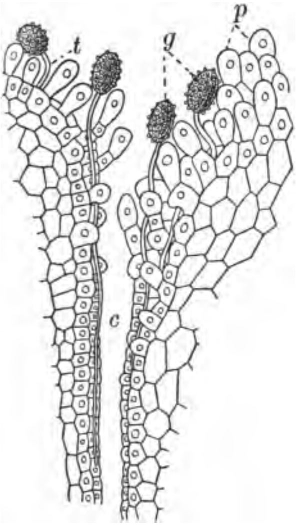


Fig. 230. Germinating pollen grains

The pollen grains (*g*) have been deposited upon the stigma. The roughened surface of the stigma is made by cell extensions, or papillæ (*p*). Pollen tubes (*t*) grow from the grains through the tissue or along the central canal (*c*) until they reach the ovule. Only a small part of the stigma and style are shown in this cut

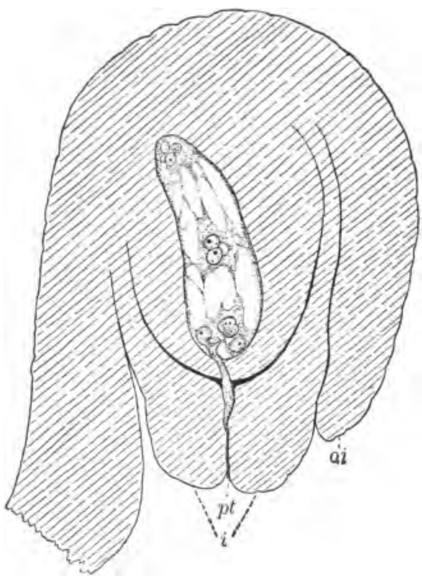


Fig. 231. Diagram of the ovule of an angiospermous plant, showing the parts of the ovule

The outer integument (*oi*); the inner integument (*i*); the micropyle, which is the opening between the parts of the inner integument; the pollen tube (*pt*), which has grown through the micropyle

which contains the ovules, it turns across to the micropyle of the ovule. It then grows through the tissue at the tip of the ovule to the end of the embryo sac (fig. 231). In some cases (elm and walnut) the pollen tube grows down to the base of the ovule, then up through it, and finally reaches the egg.

During the growth of the pollen tube the single cell which at first was in the pollen grain has developed until it now consists of three cells, which are carried near the tip of the tube. Two of these cells are male cells and can serve as sperms, although they are not ciliated. The other cell is a nutritive cell, which goes forward with the tip of the pollen tube and is an important factor in its growth. These cells all pass out of the tube through an opening in its tip when it has reached the embryo sac. One of the male cells unites with the egg cell, and in many cases, perhaps generally, the other male cell passes to the center of the sac and unites with the endosperm cell. The first union of cells is like that of the gymnosperms, but the second does not occur except in the angiosperms. This union of both the male cells with other cells in the same embryo sac is known as double fertilization. After fertilization the egg grows into a new plant, and the endosperm cell grows into the endosperm, or food material, that is stored in the seed around the embryo plant. Double fertilization gives to the seed outside the embryo, as well as to the embryo itself, the characters of both parent plants. In this way, when plants such as different kinds of corn are crossed, the ear thereby produced will have some grains showing the characters of both parents.

287. The new plant. The way in which the fertilized egg grows into the new plant is striking. The egg cell first divides and redivides in such a way as to form a chain of cells. One end of this chain may become elongated and, as the *suspensor*, may attach the developing embryo to the wall of the embryo sac. The cells at the other end of the chain are the ones that produce the parts of the new plant — the stem tip, leaves, and root tip (fig. 232). The embryo in some kinds of angiosperms has but one leaf, which grows at the end, and the young stem is at the side of the embryo. These are the angiosperms with one seed leaf, or the *monocotyledons*. In other cases the embryo may have two (or even more) seed leaves, and the stem is at the tip and the leaves are on the sides of the embryo. These are the *dicotyledons*, or plants with two seed leaves.

While these developments have been taking place in the embryo sac, the integument walls have become dry and hard, so that, by the time the young plant has differentiated the root, stem, and leaf regions, it is usually inclosed by hard and dry walls, and the whole structure is a seed. In some cases the seed is dropped from the parent plant at once, and may begin its growth immediately. Seeds may lie dormant on the ground until the return of spring, or may in some cases lie dormant for several years, and still retain their vitality. The seeds of the cocklebur and of some desert plants may lie in the ground for several years and then grow. The seed coats sometimes become so dry and hard that the water and air necessary for germination cannot penetrate, and this condition remains until, through decay of the wall or through injury to it, the needed materials can get into the seed. Most seeds, such as wheat, corn, and oats, lose their vitality within a few years at the most.

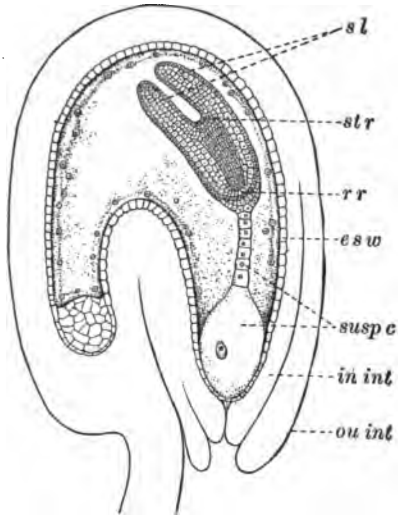


FIG. 232. Diagram of the ovule, embryo sac, and embryo of the shepherd's-purse (*Capsella Bursa-pastoris*)

The parts shown are the outer integument (*ou int*), inner integument (*in int*), embryo-sac wall (*e s w*), suspensor cells (*susp c*), root region (*r r*), stem region (*st r*), and seed leaves (*s l*)

288. The fruit. The relations between seed and fruit are not easily defined, for the reason that the fruit may include a few or many structures. The ripened ovule containing the embryo is the seed. Sometimes structures other than the seed ripen with it; regardless of how many things ripen with the seed, all are included in the term *fruit*. In the sunflower the

ovary wall ripens as a close-fitting, thin coat about the seed, and the kind of fruit thus formed is called the *achene*. In the stony fruits, as in the peach and apricot, the ovary wall divides; the inner part produces the hard covering about the seed, and the outer part produces the pulpy flesh. In the apple the calyx is joined to the wall of the ovary, the seeds are inclosed in the ovary cavities, the ovary wall ripens, thus becoming the core of the apple, and the calyx ripens into the greater part of the fruit. A transverse or a longitudinal section of an apple or pear will usually enable one to determine what part of the fruit is the ripened calyx and what part is the ovary wall.

In some cases whole clusters of flowers and the modified portions of the stem upon which they grew may ripen into a single fruit; or the pistil may grow while the seeds are developing, as in the beans and peas, so that the ripened pod is hundreds of times as large as the pistil was when fertilization took place.

The distribution and germination of seeds was fully discussed in previous chapters, and if those chapters are briefly reviewed at this time, it will be found helpful.

289. Evolution of plants. The four great divisions of the plant kingdom, and the most important classes of these divisions, have been discussed. It must have been apparent to most students that constant increase in the complexity of plants was encountered as we passed from lower to higher groups. This increase in complexity appears in the nutritive parts of plants and in the parts that have to do with reproduction. The process of gradual development from simple to complex is the process of evolution. Indeed, there may also be evolution in the opposite direction, as occurs when, through long and constant changes, simple forms are derived from complex ones. Usually evolution is thought of as having to do with increase in complexity rather than with decrease. The oldest plants of the earth were very simple, and from them, in one way or another, more complex ones have developed. The simplest plants that are now living have doubtless

changed greatly from the oldest simple plants. While, therefore, we compare one living group with another, we must keep in mind the fact that a higher group of living plants has not necessarily developed from one of the lower living groups, but rather that in past ages a common ancestry gave rise to both. The lower group has probably changed less than the higher one. It is like two streams of water that have their source on the top of the same mountain; though their source is essentially the same, the conditions under which they flow may make the two rivers quite unlike when they reach the valleys below.

290. Brief summary of the groups.[1] The thallophytes consist of simple plants, some of which (the algæ) possess chlorophyll, by means of which they manufacture their own foods. Other thallophytes (the fungi), being without chlorophyll, cannot make their own foods and are dependent. Dependency is expressed in types of parasitism and saprophytism, which are often of importance to other living things. These simple plants are prostrate and are not differentiated into roots, stems, and leaves. While reproduction is simple in this first group, in some plants we find specialized sex organs, with sperms and eggs for the formation of sex spores.

In the bryophytes the moss exhibits a much more complex type of plant. It has an alga-like stage; then it sends up leafy shoots, which expose chlorophyll to the light in a better way than appeared in the thallophytes; these shoots also bear highly differentiated sex organs. From the sex spore there grows a special asexual spore-forming stalk and capsule, from

[1] No attempt is made at this time to give a complete summary of all the important characters of the groups studied; the aim has been rather to state only the most important things which will cause each group to stand out with some individuality and at the same time give it some relation to the series of groups as a whole. Neither is any attempt made in this book to present the evolutionary series of plants. The groups are presented so that the increasing complexity is apparent, but the close evolutionary connections are omitted, and the emphasis that is sometimes placed upon evolution is here placed upon securing an elementary idea of the kinds of common plants that are found in each of the great groups.

which many asexual spores are formed. In both reproductive and nutritive work the bryophytes are much more complex than the thallophytes.

The ferns have woody tissue and often have immense leaves and are well equipped to do chlorophyll work. They often store in one year food which serves in part for the growth of the next year. Asexual spores are formed in great numbers by means of highly specialized sporangia. These spores, when they germinate (as in the case of the ferns studied), produce chlorophyll-bearing, independent plants, which grow in obscure places and produce sex organs by means of which sex spores are formed. From the oöspores new leafy fern plants grow.

In the spermatophytes we have the most important and most prominent plants of the earth. They have vegetative structures that are very much more complex than are those of any of the preceding groups. These vegetative structures are so widely differentiated as to meet the demands of almost any conditions. The flower and the seed are special reproductive structures which, with successful vegetative structures, seem to have given these plants their position of ascendancy in modern plant life.

291. Classification. Throughout this book many illustrations of the seed-plant group of the plant kingdom have been used. Although but a few of these illustrations are cited here, enough are given to enable the student to relate the classification of spermatophytes to that of preceding groups.

GROUP D. SPERMATOPHYTES

- CLASS I. GYMNOSPERMS. Genera used as illustrations — *Pinus* (pine), *Picea* (spruce), *Juniperus* (juniper), *Sequoia* ("big trees" and redwoods)
- CLASS II. ANGIOSPERMS
  - SUB-CLASS I. MONOCOTYLEDONS. Genera used as illustrations — *Lilium* (lily), *Zea* (corn), *Triticum* (wheat), *Avena* (oats), and many others
  - SUB-CLASS II. DICOTYLEDONS. Genera used as illustrations — *Quercus* (oak), *Capsella* (shepherd's-purse), *Pyrus* (apple and pear), *Rosa* (rose), and many others

PROBLEMS

1. In what ways are the seed plants the most complex of all plants?

2. What different kinds of structures in various seed plants may remain dormant throughout drought or winter, and later continue the growth of the individual plants to which they belong?

3. Show ten ways in which the seed-plant habit of storing food in seeds and elsewhere is important to industries. What four plants are most valuable for their stored food?

4. What plant products are being used as substitutes for animal products, as cottolene for lard, etc.? Are there good reasons against such substitution?

5. How may man vary the amount or quality of food stored in plants?

6. What cases are there in which man has varied plants until they would probably be unable to maintain themselves in nature if unprotected?

7. What is meant by the statement that the angiosperms are the youngest and most successful group of plants?

CHAPTER XIX

PLANT INDUSTRIES

292. Origin of plant cultivation. In the various chapters of this book we have constantly recognized the relation of plants to the common interests of men. It is important, however, that special uses of plants in the industries should receive separate attention.

In the early stages of civilization plants were used by men for food, clothing, and fuel, for the construction of houses and boats, and in many other ways. In order to obtain those plants that would best serve any of these uses, some observation and experiment with plants doubtless had to be made. Indeed, primitive people are often well versed in the nature of wild plants, so that they know what to select and where to find the desired plants in the seasons when they are available. Wild plants that were good for food or possibly for medicines were cared for early in the history of civilization. We can only guess at the ways in which they were first watched and protected, but they were cared for by people who foresaw a need for the products of these plants when mature. With such activities as these agriculture came into existence. At this time comparatively little was known of the nature of plant life, and therefore early agriculture was relatively simple. As more has been learned about plant life, plant products have improved in quality or in quantity, or in both. As populations become more dense, greater demands are made upon plants as a means of supplying adequate food and clothing.

293. Problems of plant industries. Each of the plant industries involves two kinds of problems. First, there is the problem of carefully applying what science has already discovered

about the growth of plants. This requires a knowledge of the facts that are known about the structure of plants, the conditions of soil, temperature, moisture, etc. under which they thrive best, the nature of plant and animal diseases and the means of preventing them, and the best methods of utilizing plant products after the plant has made them. Second, the life of a plant, like that of an animal, is a very intricate matter, and there are many highly important questions upon which science as yet has little positive knowledge. Each plant industry, therefore, involves many unsolved problems, about which we need to secure additional knowledge. Thus, science has discovered what kind of cultivation will best enable the corn plant to thrive; but, although botanists know the life cycle of the smut which attacks corn, a practical and thoroughly effective way of preventing the attack has not yet been found.

294. The sugar industry. Nearly all plants that do the work of photosynthesis produce sugar of some kind. In some plants the amount produced may be extremely small, and it may remain as sugar only for a brief period before it is made into some other compound and assimilated into living substance or stored within the plant. In other plants the amount may be large, and may be retained as sugar for long periods. It may be stored as sugar or, more often, as starch, which is usually changed to sugar again for transference through the plant. Plants of the latter class may prove useful in the sugar industries. It is possible that wild plants may yet be found that are valuable for this sugar content, but at present a few species produce the sugar of the world. The sugar maple (*Acer saccharum*) (fig. 233) has long been used as a source of sugar. Other species of the same genus produce sweet sap, but not so abundantly as the sugar maple. The tree belongs to the type of primeval forest that prevailed in the north-central and northeastern parts of North America. In early spring the previous season's surplus of sugar is transported to the parts of the tree where, a little later, there is active growth of new leaves. This stored sugar is used in

the early spring growth of new parts of the plant or in replenishing old parts, or may even be retained until another year. The passage of sugar-laden sap is through the youngest fibrovascular bundles. By boring a hole through the dead bark into this region, sap may be withdrawn. When it is secured in sufficiently large quantities, the water may be evaporated from it until thick sirup or sugar remains. Ordinarily

FIG. 233. Sugar-maple trees which have been tapped every year for over eighty years

The trees are tapped by boring into them so as to reach the sapwood; then a tubular spile is driven into the hole, and a bucket is suspended upon a hook on the spile. In this way the sap is caught in the bucket

a good sugar-maple tree produces 15 or 20 gallons of sap in one season, though this amount may be greatly exceeded by especially good trees. The percentage of sugar in the sap varies widely in different seasons and between different trees in the same season, but usually it is from 2 to 3 per cent. Individual trees produce in one season from half a pound to 7 or 8 pounds of sugar. Maple sirup is the partially evaporated

maple sap and, as ordinarily used, it contains from 30 to 40 per cent of the water originally in the sap.[1]

The sugar-making season is short, because, as soon as new protoplasm is developed in great abundance, the sap no longer makes acceptable sugar. Maple trees may be used from year to year indefinitely without apparent injury due to the withdrawal of sap, but the stem may be weakened by too frequent boring at one level, and the wound, though it heals in one or two years, may serve as a place of entrance for disease organisms.

FIG. 234. A Cuban sugar-cane field

Standing cane is seen at the left, between the men and the trees; in the foreground the men are loading sap-laden stalks upon the carts. Note the heavy soil covering of leaves that have been stripped from the sugar-cane stalks

Sugar-maple groves are being planted in some places for the sugar product, but other plants of more rapid growth and larger sugar production will doubtless prevent maple sugar from entering largely into sugar consumption. The distinctive flavor of maple sugar and sirup, however, will enable it to continue as a highly desired article of commerce.

[1] "The Maple Sugar Industry," *Bulletin 59*, Bureau of Forestry, U.S. Dept. Agr., 1905; "Maple Sap Sirup," *Bulletin 134*, Bureau of Chemistry, U.S. Dept. Agr., 1910; "The Production of Maple Sirup and Sugar," *Farmers' Bulletin 516*, U.S. Dept. Agr., 1912.

About one third of the world's supply of sugar comes from the sugar cane (*Saccharum officinarum*), which has at least a dozen varieties that thrive in tropical and sub-tropical countries (fig. 234). This plant has a very heavy root system, from which several stalks grow. Its leaves are large and numerous, so that much chlorophyll work is possible; hence much sugar may be made by the plant. The stalks when full-grown are so well filled with sugar-laden sap that natives often use them directly as food. The sap from good cane may contain from 17 to 18 per cent of sugar. After the leaves are stripped off, the stalks are cut and the sap is pressed from them by means of machinery specially designed for that purpose; after this the water is removed from the sugar by evaporation. Some sugar cane is grown in this country, but sorghum is more widely distributed and produces a sirup that is extensively used.[1]

Sugar beets (*Beta vulgaris*) have been grown in Europe for many generations, but it is only in recent years that they have been widely grown in the United States. They have already become a prominent factor in the sugar industry. Sugar beets thrive in temperate climates, mature in a relatively short season, and grow well in a wide range of soil conditions. Besides these advantages, they are very productive. The sugar produced from beets is rapidly coming into general favor.[2]

295. Fiber plants. Primitive people learned to use the strong-fibered grasses and the tough bark of some trees in making bands and cords for tying various articles. Leatherwood, or moosewood (*Dirca palustris*), and Indian hemp (*Apocynum cannabinum*), often so used by the early settlers in this country, have fibers of very great strength, which, when dry, are almost as strong as leather thongs. The making of cordage from plant fibers has become an important industry. Many grasses, palms, hemps, etc. have extremely long, strong fibrovascular bundles, which, when removed and twisted together, make twines of

[1] "Sugar Cane in Porto Rico," *Bulletin 9*, Porto Rico Agr. Exp. Sta., 1910.
[2] "The Sugar Beet," *Farmers' Bulletin 52*, U.S. Dept. Agr., 1910.

great strength. The banana leaf and stem and the pineapple leaf produce some of our most highly valued fibers for cordage. These and many other fibers may be woven into mats or cloth, and some of the finest dress goods and fancy articles are made from pineapple fiber (*Ananassa sativa*). Doubtless the long list of plants known to produce valuable cordage fibers and materials for weaving might be added to materially by a thorough study of our wild plants.

The most important fiber plant is cotton (several species of *Gossypium*).[1] Some of its varieties are grown in almost every tropical and sub-tropical country, and as a source of income it is to our southern states what corn is to the central states, and wheat to the northwest. Within the seed pod of cotton the seeds are surrounded by long white fibers which are the most valuable portion of the plant. Other parts of the plant have great value, however, since the seed yields oil and meal and the stem of the plant yields fiber and cellulose which is manufactured into a long list of commercial products. As an agricultural plant cotton presents its own set of problems related to soil, moisture, cultivation, and diseases, and some of these problems are just beginning to be solved. It is doubtful if any other staple crop has such great possibilities of immediate increase through scientific study of its growth and productivity.

In temperate regions the hemp plant (*Cannabis sativa*), flax (*Linum usitatissimum*), and jute (*Corchorus capsularis*) are much grown for their fibers. In tropical countries *manila hemp* is made from fibers in the leaves and stems of one of the bananas (*Musa textilis*). *Sisal* is made from the leaves of a century plant (*Agave rigida*). Two varieties of *Agave rigida* are cultivated for this use, and several other varieties are used locally wherever they grow wild. The list of plants producing valuable fibers is a long one, and those given above are merely the leading ones.

[1] "The Cotton Plant," *Bulletin 9*, Vol. 27, N.C. Agr. Exp. Sta., 1906; "A Profitable Cotton Farm," *Farmers' Bulletin 364*, U.S. Dept. Agr., 1909.

The manufacture of paper and many articles of commerce from wood pulp has become an industry of such prominence as to endanger the supply of the softer timbers from which the pulp is made. Straw and cornstalks are sometimes used in making paper.

296. The grasses. Grasses contribute to industries already mentioned and others yet to be discussed, but in this connection we have in mind those grasses that are used directly or indirectly as food for domesticated animals. The significance of pasturage can be seen by any one who observes the use made of grasslands on any farm or ranch. Grasses furnish the chief or entire food supply for most domesticated animals throughout spring, summer, and autumn, and during winter dried grasses (hay) and the grain from grasses complete the food supply. Wild grass has been depended upon extensively, but agriculturists have found that grass production and hay crops improve as readily under scientific management in a state of domestication as do other crops. Native wild grasses, uncared for, often produce but a small percentage of the pasturage or hay that selected grasses (as blue grass and timothy), when properly planted and cared for, may produce.[1]

297. The cereals. The grain-producing members of the grass family, as wheat, oats, corn,[2] rye, barley, and rice, are the chief agricultural plants of the earth. The wild ancestors of some of these cereals are known, as in the case of wheat, oats, and rye. In some cases, as wheat, our present cultivated types do not differ widely from the ancestral types in size of heads or grains, but they differ enormously in the range of territory over which they are grown and in the amount grown on any single unit of area. In extending the range of any plant beyond its native growing place new problems arise, such as adapting the soil to it and preventing the plant and

[1] "The Improvement of Mountain Meadows," *Bulletin 127*, Bureau of Plant Industry, U.S. Dept. Agr., 1908.

[2] E. M. East, "A Chronicle of the Tribe of Corn," *Popular Science Monthly*, **82**: 225–236. 1913.

animal enemies that the plant may encounter in its new growing place. Thus when corn, which naturally thrives best as a tropical or sub-tropical plant, is grown in the north central states, the shortness of the season may not allow time for ripening the ear; but by experimentation certain varieties of corn have been discovered or developed (see chapter on Plant Breeding) in which the plant is not so large as the average, and the ear, though somewhat smaller, matures in less time. Some kinds of seed corn are advertised by the salesmen as "ninety-day corn," which means that the plant will grow and ripen a new ear within ninety days, while in case of some other varieties of corn more than double that time is required for it to mature. Furthermore, in the case of wheat some varieties are much less readily affected by the rust diseases than are other varieties; some thrive best in certain regions when planted in the late autumn (winter wheat); and others in other regions thrive best when planted in early spring (spring wheat). Every civilized or even partially civilized nation depends largely upon one or more of the cereals, and in spite of the fact that the nations have been dependent upon them for so long, the practices relative to selection of seed, cultivation, prevention of diseases, and utilization of the products have changed very little from decade to decade. The application of scientific principles to the production of cereals has already shown great possibilities of improvement in plant production, but only the most intelligent agriculturists utilize these investigations, the traditional "practices of the fathers" often dominating the majority of those who till the soil. No doubt the decades immediately to follow will bring much new scientific knowledge about the growth of cereal crops, and nothing seems more fundamental than the application of those sciences which may lead to a more effective production of the world's food supply.

298. Horticulture. Fruits and berries have constituted a considerable part of the food of men throughout the period covered by history. Wild apples, grapes, and berries, in nearly

all temperate regions, have been and are still extensively used. But selection and improvement from these wild ancestors have given us varieties greatly superior to the wild types. Even to-day, however, there are many people who plant fruit trees and act as if they believed that the tree should live and produce as an essentially wild plant. The plants which are the basis of horticulture have many things in common with all other plant life. They must have suitable soil and moisture, proper exposure to the light, freedom from destructive enemies, and proper cultivation, else they cannot manufacture their own food material and the fruit which men want to produce. Most of the soil of the United States is good for horticulture if men will do the things necessary for proper production of fruit. Distant regions may for a time seem attractive to fruit growers, on account of their freedom from diseases, but diseases eventually enter even these distant regions and affect the crop. Migration to new territory is not nearly so important in fruit growing as a thorough study and application of the science of horticulture.

FIG. 235. An old grafted apple tree

This illustrates an old and well-nigh discarded method of stem grafting. The stock is much larger than the scion, owing possibly to imperfect union of tissues and possibly to difference in normal rate of stem thickening. The absence of proper care in pruning this tree is a feature too often seen

Grafting has long been practiced in horticulture (sect. 87). Parts of two individuals of closely related plants may be made to unite their woody tissues and grow as one plant. If one has a particularly desirable variety, he may insert small branches (scions) from it upon other less valuable related stock plants. The growing tissues (cambium) of the two, if united, will enable the pieces to grow together and continue to live essentially as one plant. In former practices the grafts were usually made aboveground and were probably made less effectively than they are now. If one visits an old orchard he is likely to see evidence of these grafts on the main stem or on the branches of old trees (fig. 235). The difference in size of stock and scion in old grafts may be due to a difference in the natural rate of thickening of wood in the two, or to imperfect joining of tissues, which causes a lodgment of food material and a consequent unusual growth on one side of the graft. The advantages of grafting are great. Vigorous plants which produce poor fruit or scanty fruit may be used in extending the production of especially prolific plants that produce fruit of unusually good quality. The same general principles apply to the culture of flowers as to fruit culture, and the possibilities are equally great.

FIG. 236. A properly pruned cherry tree, the remaining branches full of flowers

Photograph by the Michigan Development Company

Pruning has been found to increase both the quality and the quantity of fruit. Sometimes it is done solely for increase in quality, as when all but one or two buds of a chrysanthemum or tomato are removed, so that all the strength of the plant is thrown into the development of one or two specimens of great size and beauty. In fruit orchards it has been found that the removal of the old or surplus branches stimulates the production of flowers and fruit. There are many orchards of good vigorous trees which might be made productive simply by pruning (see figs. 236 and 237). Pruning properly done not only stimulates the production of fruit but also helps to keep the tree in such form that the load of fruit will be supported and easily gathered when mature. In pruning dead and living branches care should be taken to prevent the entrance of organisms that induce decay. A coating of paint or of tar upon the fresh wound usually prevents infection, but old wounds need to be cleaned out, sterilized, and filled with cement.

Fig. 237. A well-pruned peach tree just past the flowering period

Photograph by the Michigan Development Company

Spraying to remove or prevent disease is an important branch of horticulture; fruit and berry plants are subject to an increasing number of diseases, both plant and animal in their nature. The subject of sprays and spraying is too extensive for discussion here. It must be remembered, however,

that a tree or a bush filled with a large amount of perfect fruit or berries is not a usual occurrence in nature. Horticulture attempts to use the plant as a machine for producing a large amount of perfect fruit; to secure this result we must make careful use of every known agency that will help the machine to work well and that will protect it from those things that in nature would injure it or reduce the value of its product. The state agricultural experiment stations publish instructions for spraying orchard and garden plants.

299. Gardening. Gardening has to do in the main with the production of plants whose growing parts men use for food. The list of plants thus used is a long and constantly increasing one, and although the gardening industry is extending rapidly, it is not keeping pace with the increasing demands for its products. Both vegetable and flower gardening have problems distinct from those of other plant industries. Both are highly intensive in their nature and present new problems in such matters as soil selection and replenishment, cultivation, harvesting, marketing, and the prevention of disease.

Wild plants of many kinds are used as medicines, and some of these are grown in large quantities in gardens especially designed for that purpose.[1]

300. Plants and the soil. The plants that constitute the basis of plant industries depend in large measure upon their relation to the soils in which they live. Soils are very different from one another, some by their nature prohibiting the life of certain kinds of plants and making possible the growth of others. Some of the facts about differences in soils are known, others are matters of vigorous argument between scientists, and still other problems are recognized by all as still wholly unsolved. That the structure of the soil has much to do with its appropriateness for plant life is generally recognized. Our coarsest gravelly soils consist of much rock

[1] "Wild Medicinal Plants of the United States," *Bulletin 89*, Bureau of Plant Industry, U.S. Dept. Agr., 1906; "American Medicinal Leaves and Herbs," *Bulletin 219*, Bureau of Plant Industry, U.S. Dept. Agr., 1911.

material, with a minimum amount of decayed material from plant and animal life. If the water level is below such soils, the water runs away and there is left in the soil little available moisture and little available organic matter. In sandy soils the rock has been broken by weathering processes, sometimes aided by the action of plant life, until the rock particles are small. The coarseness of the sand depends upon the extent to which the rock particles are broken. They may have been crushed and worn into pieces so small that clay is formed and the separate grains can be seen only by magnification.

Water may be in the soil either in the spaces between soil particles or adhering to the particles. As the soil becomes finer its ability to retain water increases. This is due to two facts: first, that water adheres to the surface of the soil particles; second, that the larger the number of particles within a given volume the greater is the surface exposed.[1] Also, soil with fine-grained sand will hold the products of decayed plant and animal life better than rocky soils. Soils are classified into many kinds, according to the size and nature of the rock material and the nature of the plant and animal material contained. The leading kinds are *gravelly soils*, containing small pebbles which usually show by their form and sometimes by their markings the kind of treatment they have undergone; *sandy soils*, in which the rock material is more uniform and has gone farther in its reduction; *clay soils*, whose particles are so small and fit together so compactly that the rock origin is not very evident; *peaty soils*, containing comparatively little rock material but much more of the products of partial decay of plant and animal bodies. There are all possible gradations between these different kinds of soils. The chemical and physical nature of the rock-and-humus content of soils has much to do with their relation to plant life.

[1] This may be shown by calculating the surface of a cube ten inches in diameter, then cutting it into one-inch cubes and calculating the surfaces of these, and then comparing the surface of the original cube with the sum of the surfaces of those made from it.

301. Water drainage. The amount of water in the soil varies and depends upon many factors. The coarse soils (gravel and coarse sand) soon become dry when there is little rainfall and no replenishment of water from below. Fine-grained soils which contain a good supply of organic matter may become filled with water and may retain this water for a long time. They may become so filled with water as almost entirely to exclude the air of the soil, thus suffocating the roots of plants. But some air remains in all soils, even below ponds and streams, and some water plants can live with their roots in such water-logged soils. From 50 to 60 per cent of the total water-holding capacity of soil is found to be best for the growth of cereals. Our agricultural plants, except rice, cannot endure water-logged soils, and drainage has often been necessary to bring about a more favorable water-and-air content of cultivable lands.

Natural drainage may be either on the surface or underground. It is evident that in cultivated soils extensive underground drainage will in times of heavy rains hasten the removal of surplus water and at all times will facilitate better aëration of the soil. The annual rainfall in the United States varies from ten inches or less to more than sixty inches per year, and when any considerable part of this rainfall comes in a short period of time, non-enduring plants will suffer and sometimes be drowned unless adequate drainage is supplied.

North America still has immense tracts of waste swampy land that only needs drainage and tillage to make it highly productive soil. It is estimated that the United States has nearly 100,000,000 acres of swamp land, much of which is drainable, and in many places trained engineers are devising the needed drainage systems, and the land is being reclaimed.

302. Influence of cultivation on water supply. In earlier times agriculturists advised against cultivating corn and other crops during times of drought, because they thought that, if constantly stirred, the soil would lose its moisture more rapidly.

People now know that it is of the greatest importance to till the soil during droughts, in order that it may not lose its moisture. An illustration will help in understanding this. If two pieces of loaf sugar are placed one upon the other, the lower one held in the thumb and finger and the other left lying loosely upon the first and not touching the fingers at all, and if the lower one is then placed in contact with water, two important facts are shown: The lower piece takes up water freely, but the upper one, though lying upon the lower wet piece, becomes wet only after a long time. Close connection between the solid particles is necessary for the rapid upward passage of the water.

When soils are compact, moisture from the deeper portions passes upward freely, as in the lower lump of sugar, and evaporates into the air. If, however, the surface is kept loose and finely pulverized, so that the particles are less closely connected, moisture does not readily pass through it, and there is not so much loss from evaporation. The roots of plants, being more deeply placed, are in contact with the moist soil from which a supply of water may be secured. The depth to which roots are known to go in regions where the water is found only at great depth is discussed in section 22.

It has been generally supposed that tilling the soil serves the twofold purpose of regulating the moisture supply for growing plants and of preventing the growth of weeds. Experiments upon the cultivation of corn seem to show, however, that if all the weeds are removed without disturbing the soil, the yield is practically the same as when the soil is tilled.[1]

303. Dry farming and irrigation. In regions with a very scanty rainfall frequent tillage of the surface seems to enable the soil to hold most of the water that falls, and in this way a crop may be grown, sometimes every season and sometimes every second season. Evidently much work is necessary to enable the soil to accumulate enough moisture to supply the needs of

[1] "The Weed Factor in the Cultivation of Corn," *Bulletin 257*, Bureau of Plant Industry, U.S. Dept. Agr., 1912.

a crop.[1] It now seems probable that certain drought-resisting plants, as some kinds of wheat,[2] will make it possible to use soils which have not been usable because of inadequate moisture.

In regions where available water supplies exist, irrigation is practicable. Between 15,000,000 and 20,000,000 acres of land are said to be under irrigation in the United States, but this area is small compared with the large extent of our so-called desert lands, which only need water and proper cultivation to make them highly productive.

304. Effect of living things in the soil.[3] Microscopic plants and animals of many kinds and in great numbers live upon one another, upon plant roots, or upon dead organic matter in the soil. The roots of living plants, the molds, and the burrowing animals, such as the larvæ of insects and the earthworm, constantly take from, add to, or otherwise change the soil. Earthworms eat their way through it, and as they do so they make it more porous and excrete materials that add to the soil's available organic matter. Certain groups of soil bacteria have already been discussed (sect. 191). The living things of the soil may be said to constitute an extensive and intricate group of plants and animals living close together and greatly affecting the nature of the material in which they live. Some of the products of the soil inhabitants are helpful to agricultural plants and some are harmful.

305. Quality of soil and growth of plants. A comparison of plants of the same kind that have grown in different regions readily shows that soils differ widely in their ability to support vegetation. Even the different parts of the root system of one plant illustrate this fact (fig. 238). Soils that are at one time fertile may lose that fertility, as may be seen in any farming region. Many studies are being made, to determine how fertility is lost and what will restore it, and while the question

[1] "Dry Farming in Relation to Rainfall and Evaporation," *Bulletin 188*, Bureau of Plant Industry, U.S. Dept. Agr., 1913.

[2] Native wheat which is thought to be primitive has been found growing wild in arid districts in Palestine.

[3] See Marshall, Microbiology, P. Blakiston's Son & Co., Philadelphia.

is not settled, notable experiments that have been carried on at the experimental station at Harpenden, England, since 1848 will show the nature of some of these studies. Certain crops have there been grown year after year upon the same soil. A barley field which has been unfertilized since the experiments began, produced, in the year 1849, a little over 40 bushels per acre. Each year thereafter, with no fertilization,

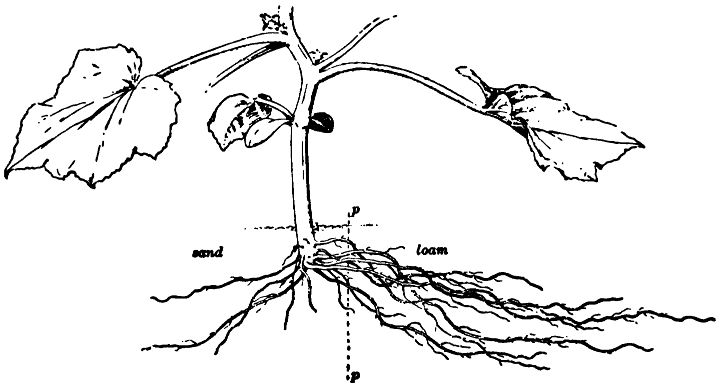


FIG. 238. Effect of quality of soil on growth of roots

The cucumber plant shown in the figure was grown in a shallow box, one end of which was filled with sand and the other with rich loam. The seed was planted in the sand, quite near the partition (p) of mosquito netting which separated the sand from the loam. When the plant was one foot high, the earth and sand were washed away and the roots sketched. Those grown in the loam weighed nine times as much as those in the sand. Three eighths natural size

barley has been grown on the same field, and the yield has steadily decreased, so that during the twenty years ending with 1909 the average per year was less than 15 bushels per acre. Another piece of ground was used for wheat, turnips, and clover in rotation (with three years given to each rotation), and was fertilized by the use of nitrogen and mineral fertilizers. Considering only the wheat records, we have the following: In the first twenty years the average yield of wheat for the years in which wheat was grown was 35.3 bushels per acre; in the second period of twenty years 32 bushels per acre was

the average yield; and in the third period of twenty years the average yield was 36.4 bushels per acre. In the second twenty-year period one year of general wheat failure materially reduced the average for that period.

The benefits that are derived in plant industries from rotation of crops are universally recognized by scientific students of the matter, but the explanation of the results secured furnishes material for active discussion. Within the last decade it has been shown [1] that at least some cereals excrete and leave in the soil substances that are injurious to the kinds of plants which produced them. These plant poisons may be the cause of loss of fertility of soil, or loss of fertility may be due to the fact that the soil has been exhausted of the available materials needed in the growth of plants. Soil replenishment through use of fertilizers may possibly bring in a new supply of available materials, may neutralize or counteract the injurious excretions within the soil, or may merely change the physical nature of the soil so as to make it more favorable to plants. Whatever the scientific explanation, the great value of natural fertilizers and of rotation of crops in replenishing soils is evident to any practical student of soils.

306. Loss of soils. In some places the chief danger is not primarily that of loss of fertility, but loss of the soil itself. It may be washed or blown away or removed by fire. If a pane of glass that has been moistened with oil is exposed for a time to the wind on a dry day, and then examined with a strong magnifying glass, it will furnish a good demonstration of the dust-carrying power of moving air. Windowpanes in the houses near the end of Cape Cod finally become translucent, like ground glass, from the action of sand driven by the wind. When cultivated fields become dry, the wind may carry away large quantities of soil.

[1] O. Schreiner, and H. S. Reed, "Some Factors influencing Soil Fertility," *Bulletin 40*, Bureau of Soils, U.S. Dept. Agr., 1907; also "The Production of Deleterious Excretions by Roots," *Bulletin 34*, Torrey Botanical Club, 1907.

Rapidly running surface water often carries away part or all of the fertile soil.[1] In grasslands, meadows, and forested areas surface water is retarded in its rate of flow, and consequently does not carry away much soil. In regions that were once forested and from which the timber has now been largely

FIG. 239. Erosion of the soil following removal of the forest

This land was covered with a heavy pine forest and had a rich soil, which was held upon the forest floor. When the timber was removed, erosion soon cut ditches through the pasture land, and part of the rich soil was washed away

removed, the surface water soon erodes ditches (fig. 239), which, with rapidly deepening channels and developing tributaries, will in a few years carry away much of the fertile soil of the forest floor. After forest fires, which themselves destroy much of the humus of the forest soils, the surface water, which is no longer retarded and absorbed by humus, flows

[1] "Soil Erosion," *Bulletin 71*, Bureau of Soils, U.S. Dept. Agr., 1911.

with increased rapidity. In so doing it carries away large quantities of soil, sometimes uncovering the burned roots until the trees are easily overturned by winds.[1]

There are several means of preventing much of this loss of soil by erosion. In wooded regions judiciously cutting part of the timber each year, rather than cutting all of it at once, gives opportunity for new plants to occupy and hold the soil. There are many kinds of soil-holding plants which, if properly placed, will prevent erosion in its earliest stages, and these should be used. In open, hilly fields which are exposed to erosion, grass and meadow crops are desirable, since their roots help to hold the soil throughout the whole year. In such cases the roots and stems help to prevent the rapid run-off of the surface water. The very things that need to be done in the cultivation of plants increase the danger of loss of soil where rapid flow of the surface water cannot be prevented.

In hilly fields it is often difficult, sometimes impossible, to prevent erosion. In some localities the rows of growing plants are arranged across the slope of the hill; this arrangement helps somewhat in retarding the surface flow of water. If cultivation is continued in such places, the soil sooner or later becomes eroded, and it is with extreme difficulty that any plants gain a foothold (fig. 240). In some foreign countries hillsides have been saved for cultivation by a process of terracing. The terraces are constructed in such a way that the soil upon each is level or slopes toward the hill, thus retarding or preventing erosion. Such terraced farms are sometimes most desirable for vineyards, but it is obvious that for ordinary crops these elaborate processes of terracing, and the constant care required, will prove profitable only where available land is extremely scarce. In many localities where the slope of the surface is moderate enough, underground drains may be laid to take care of the surface flow and thus prevent erosion except at times of extremely heavy rains.

[1] "The Movement of Soil Material by the Wind," *Bulletin 68*, Bureau of Soils, U.S. Dept. Agr., 1911.

307. Air and temperature. In the earlier sections of this book the air relations of plants have been presented in the various discussions of photosynthesis and of plants of different regions. Under most circumstances the air is likely to contain enough of the proper gases, and not too much of harmful ones, to enable plants to thrive. In large cities and in the vicinity of manufacturing establishments, especially smelters, harmful gases are present in quantities that often kill plant life. For fifteen miles or more about certain copper smelters all plant life has been killed. In commercial greenhouses and in homes the plants may exist in the presence of illuminating gas, but 1 part of illuminating gas in 80,000 parts of air will prevent carnations from flowering, and other plants are prevented from flowering and often killed by such gases.

In the vicinity of cement manufacturing plants the cement gets into the stomata of the leaves, becomes hard and closes the stomata, and eventually results in killing all plant life.

308. Prevention of plant diseases. The development of plant industries has tremendously stimulated the study of plant diseases. Many volumes have been written upon the topic, and every agricultural experiment station issues bulletins from time to time, to advise people about the latest discoveries in regard to the nature of important diseases and the means of preventing them. The ways in which these diseases operate are various. They may use the food material made by the host plant, as is supposed to be true in case of wheat and oat rusts; they may also consume or supplant important tissues, as when corn and oat smut occupy the grains of their hosts; they may stop the vascular tissues, as is the case with the bacteria that produce the brown wilt of cabbage and other related plants; or they may excrete substances that are poisonous to the host plants.

Diseases due to animals such as plant lice or aphids, scale insects, and larger insects are extremely destructive. The intricate nature of such diseases may be shown by using as an illustration the aphids that often produce serious injury

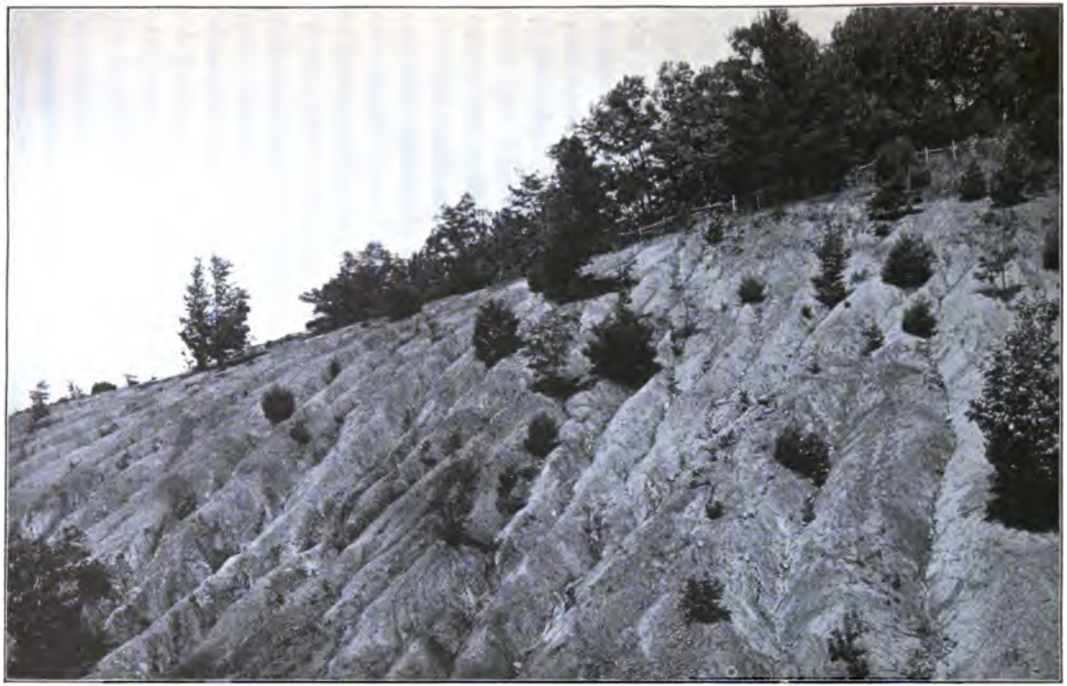


FIG. 240. A hillside which once was forested but is now washed into gullies and ridges

Not enough plants have gained a foothold to prevent erosion. Photograph by United States Forest Service

to corn. Their nourishment consists of the juices which they suck from the tender roots. They excrete a sweetish substance called honeydew, which is used as food by ants and sometimes by other kinds of insects. The aphids may begin to live upon corn when the seedling is germinating, and continue upon the growing plant until it is mature. The aphids are sluggish insects and, although they reproduce rapidly when food is abundant, they are not readily able to pass through the soil or over its surface to the roots of new plants.

There is a common black field ant which devours the honeydew, apparently with great relish. The burrows of these ants may often be seen about the bases of corn plants. They dig tunnels to the roots of the corn, then carry down some of the aphids and place them upon the roots. There the aphids are cared for by the ants, and the latter secure the honeydew as food. Throughout the summer and autumn the ants constantly care for the aphids and their young. Aphid eggs are carried to the places that are most favorable for their hatching, and when the young are hatched they are transplanted upon tender young roots. When disturbances of the soil threaten destruction to the eggs, the ants seize them as they would their own eggs and carry them away. At the beginning of the winter aphid eggs are carried by the ants into the deepest parts of the ant nests. At the return of the favorable season the eggs are brought forth again to places suitable for hatching. In this case the aphids, which are parasitic upon the corn roots, are themselves in slavery (*helotism*) to the ants, and this interrelation obviously reaches a high degree of development. When seed corn is treated with oil of lemon, the aphids are said to be repelled, for a time at least, from the young plants. Frequent cultivation disturbs the ant burrows, and birds that prey upon ants, as flickers and woodpeckers, also tend to reduce the damage done by the aphids.

309. Resistance to disease. Every kind of economic plant seems to have one or more plant or animal diseases. Each presents special problems, many of which are yet unsolved.

In some cases where solutions have not been forthcoming, attention is being centered upon securing resistant varieties of plants rather than upon preventing the disease. In open nature many plants thrive and are not affected by diseases which affect other plants of the same kind; that is, some plants are resistant and some are susceptible. Other plants may have certain diseases but are not killed by them, as in the case of the lilac and the disease known as lilac mildew. A good illustration of the value of the study of disease resistance is presented in connection with grape plants and an insect (phylloxera) which is parasitic upon the roots of the grape.

The grapes cultivated in Europe are descended from a European wild species; the principal varieties cultivated in the middle and eastern United States are descended from American wild species. Since the French grapes produced a quality of wine that differed from that made from the grapes of the United States, European grapes were brought to this country. Their roots were soon attacked and the plants well-nigh destroyed by the phylloxera. It was found, however, that the roots of the American grapes were able to withstand attacks from phylloxera and were not seriously affected by it. It was also found that when European grapes were brought to this country and grafted upon American stock, the quality of the European fruit might be secured without the accompanying dangers from the insect. But when grape growers transplanted American grapes into Europe, the phylloxera was also transferred, and soon the native grapes of Europe were attacked and serious damage was done in the vineyards of France. It was found that by treating the soil with carbon disulphide the phylloxera were killed, but this method usually proved too expensive for growers of grapes. Many French grape growers adopted the practice of planting American plants and then grafting their own grapes upon this introduced stock. The grape industry of France has been greatly increased by thus growing French varieties upon the stronger and more resistant American stock.

PROBLEMS

1. What is it that often causes suddenly submerged agricultural plants to become yellow and die?

2. What causes the bubbles that arise from the soil when a heavy shower is falling? What causes them to rise?

3. What are the worst plant diseases of your community? What has your state done to prevent these diseases? Do people in your community follow the directions of your agricultural experiment station relative to plant diseases?

4. What is the source of the dust that is deposited on window sills during windy weather?

5. Are soils blown away during windy weather?

6. Why are the branches of young trees pruned so heavily when the trees are transplanted? Why are they pruned as a means of fruit production?

7. Why do agriculturists ordinarily use low or level lands chiefly for cultivation and uplands chiefly for pasturage?

8. What effect upon the soil is supposed to be produced by rotation of crops? Is rotation advisable for the garden?

CHAPTER XX.

WEEDS

310. What is a weed? The term *weed* is not a botanical one but is a common word for the conspicuous troublesome or injurious plants. It is not customary to apply the name *weed* to lower forms of plant life, such as bacteria and fungi, even though they may be extremely harmful to field and garden crops, orchards, or forests. Most weeds are flowering plants, but horsetails and a few ferns (as the sensitive fern, fig. 216) are sometimes troublesome enough to be classed in the list.

The same plant may be counted a weed in one place and not in another. The sensitive plant, not uncommon as a curiosity in our greenhouses, is a troublesome weed over immense areas in the tropics. Wild carrots, of the same species as the cultivated ones, are a nuisance in New England mowing lands and are rapidly extending westward; field garlic, melilot, horseradish, tansy, oxeye daisy, and orange hawkweed, or "paintbrush," were all introduced as valued garden plants, afterwards becoming noxious weeds.

311. Why weeds succeed. The characteristics which enable weeds to flourish where farm and garden crops need care to enable them to grow are too numerous to be stated and explained at length in a very elementary book. Some of the important characteristics which distinguish most weeds are:

1. Great reproductive power.

2. Capacity for rapid growth, which enables them to shade and destroy other plants.

3. Ability to resist drought, shading, frost, and plant diseases.

Any very prevalent and troublesome weed will usually be found to possess a great many of the qualities just stated. A good example of this is found in the common sorrel (fig. 241). It is rapidly propagated by its creeping roots, which may form a network throughout a piece of ground nine feet in diameter. As these roots form buds at short intervals, a single plant, when let alone, will soon become the center of a colony. Sorrel also seeds abundantly, and its seeds occur mixed with commercial grass seed and clover seed. It is little affected by drought or frost and flourishes in poor, thin soils, so that neglected pastures often become overrun with it. This sorrel, then, is a good example of the kind of weed that finds its way where the conditions are not very favorable to the growth of more robust plants, and that makes considerable headway beneath the shade of crops taller than itself.

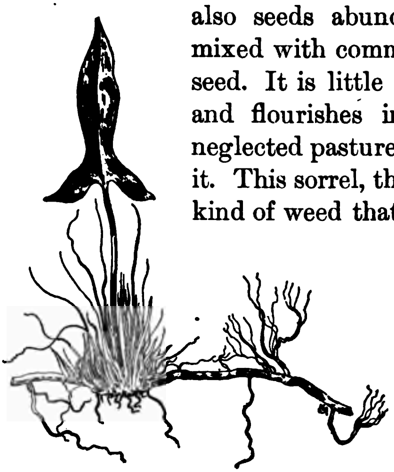


FIG. 241. Portion of a plant of the common sorrel

The leaf is drawn about one half natural size. The running roots of a large specimen would be at least sixty times as long as the piece here shown

An example of the opposite type of weed, that cannot reach anything like its full size except in deep, rich ground, is the common ragweed (fig. 242). Under favorable conditions this grows so large as to crowd out other plants. It cannot reproduce itself except by seed, but the seeds are abundant (often more than 20,000 in number); the seedlings soon become stout and branching, with a deep taproot which robs all neighboring plants of water and food materials. Other familiar weeds of rich ground with the robust habit of the ragweed are pigweeds (*Chenopodium*) of several species, two or three species of rough pigweeds (*Amaranthus*), several kinds of dock, the Indian mallow or butter print (*Abutilon*), and sunflowers.

312. How weeds injure the farm and garden.[1] Although some weeds are of use as food for man or the lower animals, and a few have medicinal properties, their presence in the farm or garden is on the whole most harmful in the following ways:

1. Weeds take moisture needed by useful plants.
2. Weeds rob the soil of valuable salts, such as nitrates and potash compounds, and it is probable that they may add secretions that are injurious.
3. Weeds shade other plants, thus weakening them by hindering photosynthesis.
4. A few parasitic weeds, like the clover dodder (fig. 243), rob their hosts of plant food.
5. Some weeds harbor parasitic fungi or insects (such as the potato beetle) which are injurious to useful plants.

FIG. 242. The common ragweed (*Ambrosia artemisiaefolia*)

The group of flower clusters at the left and the leaf at the right are considerably reduced, and the central plant is much reduced. The slender stem is characteristic of individuals grown in the shade; plants grown in the sunlight are much shorter and very robust

[1] See also Bergen and Caldwell, Practical Botany. Ginn and Company, Boston.

6. Poisonous or intoxicating plants injure horses, cattle, and sheep.

7. Some spiny plants (such as the smaller cacti) and burs (like the sand bur) may lame the feet of domestic animals. Thorny shrubs are very troublesome to woolgrowers, as they pull out much wool, and the burs greatly injure the quality of the fleece.

FIG. 243. Clover dodder, parasitic on red clover

A, habit sketch of part of the parasite and the host; *B*, portion of stem of the dodder, showing protuberances from which haustoria pass into the stem of the host; *C*, a single flower of the dodder. *B* and *C* considerably magnified. Modified after "Flora Danica"

8. Certain weeds, when eaten by cows, render milk unpalatable or ill-scented.

9. Weed seeds injure the quality and affect the price of clover and other seeds that are raised for sale.

313. Amount of damage caused by weeds. It is impossible to put into exact figures the amount of damage annually done by weeds in the United States, but it probably aggregates over $200,000,000 a year.[1]

The expense caused by weeds is largely for extra labor of men and animals,

[1] The estimate here given is by Professor Frederick V. Coville, and is based on the assumption that the loss may amount to 5 per cent of the total value of the principal crops of the United States. The estimated value of the crop of corn, wheat, oats, barley, rye, buckwheat, flaxseed, rice, potatoes, hay, tobacco, and cotton for the year 1912 was $4,693,000,000.

Another estimate by an expert in the Department of Agriculture places the loss at about $300,000,000.

but much also is expended for extra wear and tear of farm implements and machinery and for the purchase of implements which are only needed for contending with weeds. It is worth while to notice that the labor expended in destroying weeds is not all dead loss, as the loosening and turning over of the soil is often of much use to the growing crops.

Aside from the damage which they inflict on crops, weeds cause much inconvenience and loss, as they infest roadsides and railroad rights of way, and choke up streams, canals, and irrigation ditches.

FIG. 244. The buffalo bur (*Solanum rostratum*)

This is a troublesome weed in grain-fields. It is traveling eastward from the Great Plains near the Rocky Mountains. It is often distributed by being blown about as a tumble-weed. One sixth natural size

314. Where our weeds originated.[1] Among the most troublesome weeds in the long-settled portions of the country about half are of European origin and several came from tropical America and from India. Only about 40 per cent are native American species.[2]

Naturally most of the European weeds introduced into this country have traveled rather slowly inland from the Atlantic coast. Some species, like the common groundsel (fig. 19), chicory, butter and eggs, wild carrot, and wild parsnip, are still much more common in the maritime provinces of Canada and in New England than

[1] See the article "Pertinacity and Predominance of Weeds," in the Scientific Papers of Asa Gray, selected by C. S. Sargent, Vol. II, Houghton Mifflin Company, Boston; also "Farm Weeds of Canada," Second Edition, Government Printing Bureau, Ottawa, Canada.

[2] *Farmers' Bulletin 28*, U.S. Dept. Agr.

farther westward. A few weeds, like the buffalo bur (fig. 244), have made their way eastward from the Great Plains.

315. How to avoid and destroy weeds. It is often easier to keep weeds out of cultivated ground than to destroy them after they get a foothold there. The principal means of avoiding weeds are to plant as few weed seeds as possible and to allow few to be planted by natural agencies. This means that the seeds used for the farm and garden shall be as free as possible from weed seeds, that all manure used shall contain as few weed seeds as possible, and that all spots which might serve as breeding places for weeds must be carefully watched and prevented from seeding the adjacent ground. Neglected fence rows and other bits of uncultivated land may grow enough

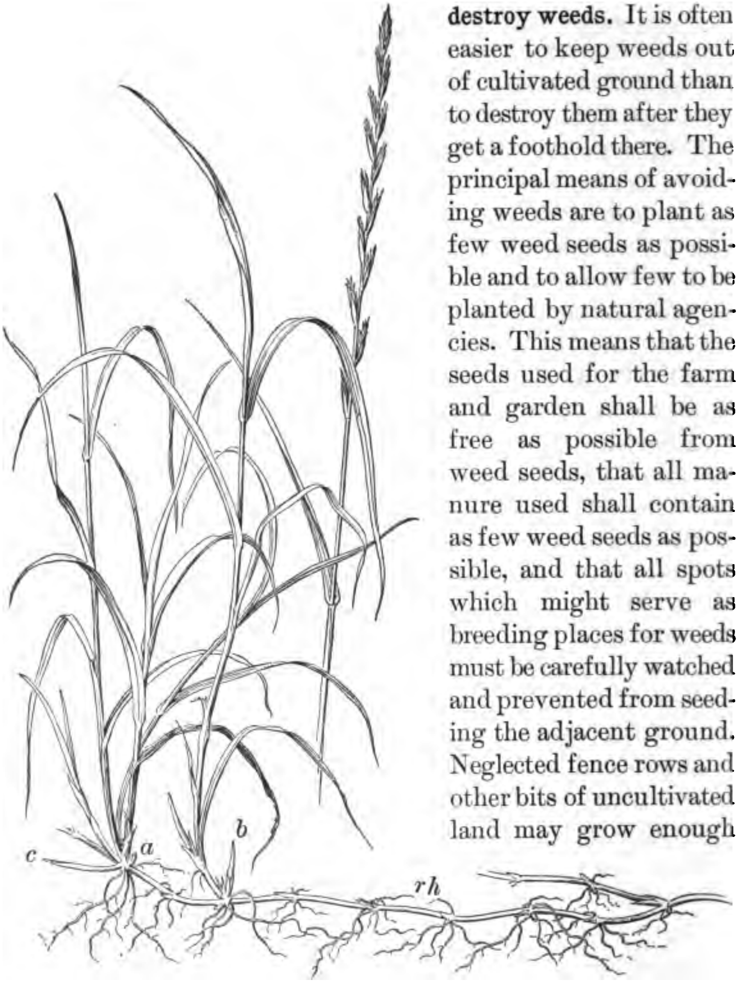


Fig. 245. Couch grass, one of the worst weeds of the northeastern states

It is rapidly propagated by its long rootstocks (*rh*). Note the manner in which young shoots (*a*, *b*, *c*) are shown arising from the nodes of the rootstock

readily transported seeds, such as goldenrod, thistles, prickly lettuce, and milkweeds, to seed all adjoining parts of the farm.

Many useful plants and still more harmful ones spread by vegetative means so as to overrun neighboring ground. In this way a blackberry patch may spread by the root so as to become a nuisance, and black raspberry bushes will travel by means of their long rooting branches (fig. 72) so as to cover much ground. Couch grass, or quack grass (fig. 245), growing beside a cultivated field or garden will soon spread into the cultivated soil by means of its vigorous rootstocks.

Fig. 246. Wild oats, a grass belonging to the same genus as the cultivated oat

It is an extremely troublesome weed, especially in fields of the small grains. After "Farm Weeds of Canada"

Methods of destroying weeds cannot be treated in detail in a textbook on botany, though a few words may be given to the subject. Weeds which have gone to seed should not be plowed or spaded under, but should be burned when dry. It will be found well worth while to rake away from fences and burn all accumulations of tumbleweeds. Wild mustard, which is a very troublesome weed in fields of the small grains, is readily killed by spraying with a solution of copper sulphate or iron sulphate. Weedy lawns are sometimes improved by very careful salting, which does not injure the grass. Gravel walks may be cleared of weeds by watering them with a highly poisonous solution of sodium arsenate or of crude carbolic acid. Rotation of crops (that is, following the crop of one year by a

very different one the next year) often rids the ground of the most troublesome weeds. Such weeds as wild oats (fig. 246), foxtail grass, and wild mustard are very injurious in fields of the small grains; they do little damage in cornfields, and changing the crop from wheat to corn for a year or two helps to reduce these weeds. Many of the worst weeds in grasslands and pastures, such as the common sorrel (fig. 241), wild carrot, wild parsnip, buttercup, moth mullein, common mullein, orange hawkweed, oxeye daisy, and yellow daisy, do little harm in cornfields. At times these weeds and many others become very harmful in grasslands. If such grasslands are plowed, and a cultivated crop, as corn or potatoes, is grown for one or two years, these weeds may be effectively removed.

PROBLEMS

1. Name five of the worst weeds of cornfields in your region; five of fields of small grains; five of grasslands. Which, if any, of these weeds are not natives of this country?

2. What is the most troublesome weed in the gardens that you know? Why? What is the best method of destroying it?

3. Give an example of a weed that thrives best in wet soil; of one that will grow in very dry soil; of one that is little injured by trampling; of one that is so offensive to grazing animals that it is never eaten by them; of one that is not killed by being uprooted and left exposed.

4. Describe the way in which the seeds or fruits of ten common weeds are dispersed.

5. Which of these kinds of seeds are very likely to be bought mixed with many weed seeds: corn, ordinary grasses, wheat, clover, beets? Explain. How is the difficulty to be avoided? remedied?

6. Give an example of a weed that is troublesome in spite of having no very efficient means of seed dispersal.

7. Try to give some reasons for the fact that a majority of our worst weeds are of foreign origin — largely European.

8. Explain why rotation of crops, such as plowing a mowing field and seeding it to corn, tends to destroy weeds.

9. Give instances of useful plants of the farm or garden that you have found growing like weeds among other crops.

10. In the following table the names in each line at the left of the vertical line are those of cultivated plants; the names at the right, those of wild plants of the same family or even more closely related. Explain in each case, as well as you can, why the cultivated plant would be unable to maintain itself in competition with its wild relatives if they were growing side by side.

wheat, corn	grasses occurring as weeds
beets, spinach	pigweeds
peonies	buttercups
garden strawberries	cinquefoils
pansies	blue dooryard violets[1]
scarlet salvia	catnip
potato, tomato	Jimson-weed, horse nettle, ground cherry
lettuce	dandelion

11. How should we treat a lawn infested with dandelions? with chickweed? with undesirable grasses?

[1] *Viola papilionacea*, *V. sororia*.

APPENDIX

PHOTOSYNTHESIS

The chemistry of photosynthesis is not completely known, but some of the simpler aspects of it may prove valuable to the student. The chemist's formula for water is H_2O, in which H stands for hydrogen and O for oxygen, and the figure 2 indicates that two parts of hydrogen are united with one part of oxygen. Similarly, CO_2 indicates that one part of carbon is united with two parts of oxygen to form carbon dioxide. When these compounds are broken up, there is, for a very brief time at least, free C, H, and O. If one unit of each compound (H_2O and CO_2) is thus broken up, there will be two H, one O, one C, and two O — or in all three O. After photosynthesis has been going on for some time, starch is usually formed. Starch consists of $(C_6H_{10}O_5)_n$. This means that six parts of carbon, ten parts of hydrogen, and five parts of oxygen unite to form starch, and the *n* means that the unit $C_6H_{10}O_5$ does not appear singly, but that an unknown number of them are united. Disregarding the fact that several of the starch units are held together, and considering the single unit $C_6H_{10}O_5$, we may be able to see what happens in the work of photosynthesis. To secure the amount of carbon necessary to form starch, six times the unit CO_2 must be taken, since six units of carbon are to be used. To secure the needed amount of hydrogen, five times the unit H_2O must be used, since there must be ten units of hydrogen, and two are secured with each unit of water. We have therefore $6\,(CO_2)$ and $5\,(H_2O)$. When the energy of the sun has broken these things into their constituent parts, there are 6 (C), 12 (O), 10 (H), and 5 (O) — or 17 (O) in all. But starch consists of

$C_6H_{10}O_5$, and in making this unit of starch there has been used all of the carbon, all of the hydrogen, and five units of the oxygen, thus leaving twelve units of oxygen to be set free or to be used by the plant in some other way. Some of this free oxygen passes into the air, though some of it is used by the plant in a later process.

The compounds thus constructed, such as starch and sugar, are called carbohydrates, the name indicating that they are compounds of carbon and water.

GLOSSARY

Abortive. Imperfectly developed, as in abortive stamens.

Absorption. Act of taking in substances through the tissues.

Accessory fruits. Fruits reënforced by ripening of stem or other structures together with ordinary fruits, as in strawberry, apple, pear, quince.

Adventitious buds. Buds that spring from various parts of the root or stem, not from nodes.

Aërial roots. Roots that develop in the air.

Akene. A small, dry, one-seeded fruit in which the ovary wall adheres to the seed, as in sunflower, dandelion, and grains of common cereals.

Albuminous seeds. Seeds that, when ripe, contain endosperm.

Aleurone. Grains of definite structure containing protein food; aleurone grains are often found in a single layer of regular cells just within the seed coat.

Alternation of generations. Alternating of a sexual and a sexless generation in the life cycle of a plant.

Ament. The flower cluster of trees and shrubs, such as oak, willow, etc.

Anabolism. Building-up processes; making and assimilating food materials.

Anaërobes. Plants that cannot carry on their life processes in presence of ordinary air.

Anatropous (turned up). Applied to ovules or seeds that grow in an inverted position.

Andrœcium (male household). Stamens of a flower collectively; this name was given when stamens were thought to be male sex organs.

Anemophilous flowers (wind-loving flowers). Those whose fertilization is effected by means of the wind.

Angiosperms (inclosed seeds). One of the two groups of spermatophytes (seed plants).

Annulus (a ring). The elastic ring of cells around the sporangium in ferns.

Anther. The pollen-bearing part of the stamen.

Antheridiophores. Stalks upon which antheridia are borne.

Antheridium; pl. **antheridia.** The male sex organ in the lower groups of plants.

Antherozoid. See *Sperm.*

Antipodal (against the foot). Applied to a group of cells at the end of the embryo sac farthest from the micropyle.

Apetalous. Without petals.

Apical. At the apex or tip.

Apocarpous (without carpels). Applied to flowers in which the carpels are entirely free from one another.

Appressed. Lying flat throughout its length, as appressed bracts.

Association. An ecological unit group smaller than a plant formation, of which the latter is sometimes made up.

Awl-shaped. Narrow, tapering to a point, as awl-shaped leaves.

Awned. Having bristle-like appendages, as in heads of many kinds of wheat.

Basidium (club); pl. **basidia.** The specialized club-shaped cells on which the spores of some fungi are borne.

Bast. The phloëm portion of a fibrovascular bundle. It may be fibrous (hard bast), or composed of sieve tubes (soft bast).

Bilabiate (two-lipped). Applied to the form of corolla in certain dicotyledonous plants.

Bract (a thin plate). The small, scale-like, modified leaves which sometimes are found at the base of the flower cluster.

Calyptra (a cover). In mosses, the hood that covers the tip of the capsule.

Calyx (a cup). All the sepals, which together form the outer envelope of a flower.

Cambium. The meristem cells of a fibrovascular bundle lying between the phloëm and xylem, and having the power of division, so as to produce new phloëm and xylem.

Capitate (relating to head). (1) Rounded, as the head of the stigma of the primrose; or (2) growing in heads.

Capsule (a small box). A dry, dehiscent seed vessel (formed of more than one carpel).

Carpel (fruit). The megasporophyll; hence either a simple pistil or one of the parts of a compound pistil.

Carpellary. Relating to a carpel.

Catkins. See *Ament.*

Caulicle (a small stem). The initial stem in an embryo.

Cell. The morphological or anatomical unit of plant and animal structure.

Cellulose (pertaining to a cell). The primary substance of the cell wall.

Central cylinder. The stele, or portion of the root or stem which is inclosed by the primary cortex.

Chaff. Small dry scales usually found in connection with the seeds of plants, as in grasses and *Compositæ.*

Chalaza. The base of an ovule where integuments and nucellus are one common tissue.

Chlorophyll (green leaf). The green coloring matter of plants.

Chloroplast. One of the special bodies that contain chlorophyll.

Choripetalous (separate petals). With the petals separate, not united.

Chromatophore (color-bearing). A general term for all bodies in plants containing coloring matter.

Cilium (eyelash); pl. **cilia.** Marginal hairs; motile protoplasmic filaments, as those of sperms.

Cleistogamous. With close fertilization, occurring in flowers before they open.

Closed bundle. A fibrovascular bundle containing no cambium; growth is closed.

Cœnocyte. A number of nucleated masses of cytoplasm (cells) inclosed by a common wall.

Collateral (sides together). Side by side, as in a fibrovascular bundle in which the xylem and phloëm are side by side in a radial direction.

Columella (a small column). The persistent axis of certain spore cases, as in mosses.

Concentric (center together). Technically used of a fibrovascular bundle whose tissues are arranged so as to surround one another.

Conidiophore (conidium-bearer). Stalk upon which conidia are borne.

Conidium; pl. **conidia.** The asexual spore of some fungi, as in potato blight and grape mildew.

Conjugation (joined together). The sexual union of similar gametes.

Connate. Applied to leaves that appear united or grown together at their bases.

Connective. The portion of the stamen connecting the parts of the anther.

Cordate. Heart-shaped.

Corm. The fleshy stem or base of a stem; a bulb-like structure, as on the underground part of jack-in-the-pulpit.

Corolla (a small crown). The inner envelope of a flower within the calyx, composed of petals.

Cortex. Rind or bark.

Cortical. Relating to cortex.

Cotyledon. A primary embryo leaf borne by the hypocotyl (caulicle) of the embryo plant.

Cryptogams (hidden marriage). A term used to include thallophytes, bryophytes, and pteridophytes.

Cupule (a little cup). The gemma cup of liverworts.

Cuticle (skin). The outermost layer of epidermis, differing chemically from the remainder of the cell wall.

Cutinization. The transformation of the outer layer of the epidermis into *cutin*, a substance which is nearly waterproof and not easily penetrated by gases.

Cyclic. An arrangement of leaves or floral organs in such a way that two or more appear upon the axis at the same level, thus forming a cycle or whorl.

Cytoplasm. The jelly-like living material of the cell.

Deciduous. Applied to plants which lose their leaves at regular intervals.

Dehiscence (gaping). The opening of an organ to discharge its contents, as in case of anthers, sporangia, and capsules.

Dermatogen (skin-producer). The layer of young epidermis in growing points.

Dichogamous. With stamens and pistils not maturing together, as in many plantains.

Dichotomous (cutting in two). Forked regularly in pairs.

Dicotyledonous (cotyledons double). Having two cotyledons or seed leaves.

Dimorphism (two structures). Having two different forms. Long-styled and short-styled flowers of the same species are dimorphous.

Diœcious (two households). Having the two kinds of reproductive organs borne by separate individuals.

Dorsiventral. Having the two surfaces differentiated so that one is upper and one lower.

Drupe. A stone fruit with a fleshy outer and a hard inner layer of the pericarp, as in the walnut, peach, plum, etc.

Ecology. The study of the relations between the plant and its environment, including the other living beings with which it has to do.

Egg or **oösphere.** The female gamete.

Egg apparatus. A group of three cells, consisting of the egg and two synergids, one at each side. Found in angiosperms.

Embryo. The young plantlet within the seed.

Embryo sac. The cavity within which the embryo develops.

Endodermis (within the skin). The layer of cells inclosing the fibrovascular bundle; the bundle sheath.

Endogenous (produced within). Originating from internal tissues.

Endosperm (within the seed). A tissue containing reserve materials developed within the embryo sac.

Endosperm nucleus. The nucleus of the angiosperm embryo sac from which the endosperm of the embryo sac develops.

Enzyme. One of the plant secretions which digest substances external to the plant, as in carnivorous plants, or reserve materials, as in seeds.

Epiphyte. A plant which grows upon other plants.

Fertilization. The act of uniting an egg and a sperm.

Fibrovascular bundles (fiber vessels). The strands that make up the framework of higher plants.

Filament (a thread). The stalk of the stamen that supports the anther; also the individual threads of algæ or fungi.

Filiform. Thread-like.

Fission (splitting). Cell division resulting in division into halves.

Fleshy. Thick, succulent.

Flowering glume. In grasses, the bract that subtends each flower, sometimes called lower palet.

Formation. An ecological group. It signifies a well-defined assemblage of plants characteristic of some kind of station.

Frond (a leaf). A name given to the leaf of ferns.

Fruit. The ripened ovary and its contents.

Funiculus (a slender rope). The stalk of an ovule or seed.

Gametangium (gamete vessel). The specialized organ for production of gametes.

Gamete. A reproductive cell which ordinarily becomes functional only upon union with another. As a result of this union a sexual spore is formed.

Gametophyte (gamete plant). The sexual stage of an alternating plant.

Gemma (a bud); pl. **gemmæ.** In bryophytes, many-celled buds specialized for vegetative propagation.

Generative cell. The cell within the male gametophyte of spermatophytes (usually within the microspore wall) which divides to form the two male cells.

Geotropism (turning toward the earth). The tendency of organs or portions of organs to go downward.

Glaucous (pale green, gray). Whitened with a bloom, like that on a cabbage leaf.

Glume (a husk). A chaff-like bract belonging to the inflorescence of grasses; the outer glumes subtend the spikelet; the flowering glume is the bract of the flower.

Gluten (glue). A term used for the glue-like products of plants, especially of seeds.

Grain. A seed-like fruit, like those of grasses, with pericarp grown fast to the seed; also any small, rounded body, as of starch.

Growing point. The group of meristem cells at the growing tip of an organ, from which the various tissues arise.

Guard cells. The cells (usually two) which open and close a stoma.

Gymnosperms (naked seeds). One of the two groups of spermatophytes (seed plants).

Gynæcium (female household). The pistil, or collectively the pistils, of a flower.

Halophyte. A plant which can thrive in saline soil, as that of "alkali" lands or salt marshes.

Haustorium (drinking organs); pl. **haustoria.** The absorbing organs of some parasites.

Heliotropism (turning to light). Tendency of plants to turn toward the sun.

Heterogamy (unlike gametes). The condition of plants whose pairing gametes are dissimilar.

Heterogamous. Pertaining to heterogamy.

Heterospory (unlike spores). The condition in plants which produce two kinds of asexual spores.

Heterosporous. Pertaining to heterospory.

Homospory (similar spores). The condition in plants which produce but one kind of asexual spore.

Homosporous. Pertaining to homospory.

Host. The plant upon or within which parasitic plants or animals develop, and from which they obtain nourishment.

Hybrid. A plant which is the offspring of an egg of one species fertilized by the pollen of another species. The term is also used for crosses between two varieties of plants.

Hydrophyte (water plant). A plant thriving only in water or marshes.

Hygroscopic (moisture seeking). Having an avidity for water.

Hymenium (a membrane). In fungi, a surface layer of interwoven filaments from which the spore-bearing filaments arise.

Hypha (a web); pl. **hyphæ.** The slender vegetative filaments of fungi which may or may not be woven into a mat (*mycelium*) or a definitely organized plant.

Hypocotyl. The short stem of an embryo seed plant.

Hypodermis (under the skin). The tissues which lie immediately beneath the epidermis and which serve to strengthen it.

Hypogynous (being under the ovary). Applied to those flowers whose stamens and floral envelopes are at the base of the ovary.

Indehiscent. Not dehiscent, or not splitting regularly.

Indusium (covering); pl. **indusia.** In ferns, a cellular outgrowth of the leaf covering the clusters of sporangia (*sori*).

Inflorescence (flowering). The arrangement of flowers; or the flowering portion of a plant.

Integument (covering). The covering of the ovule.

Intercellular. Between or among the cells.

Internode. The part of a stem between two nodes or joints.

Intine (on the inside). The inner coat of a pollen grain.

Involucre (rolled within). The leaf-like or bract-like sheath that incloses a cluster of flowers.

Irritability. The capacity which protoplasm possesses of responding to stimuli, such as light, heat, gravity, and contact with chemical reagents.

Isogamous (equal gametes). Applied to those plants whose pairing gametes are similar.

Lamina (a layer). The blade or expanded part of a leaf.

Leaf trace. The fibrovascular bundles from the leaf which blend within the stem with its fibrovascular cylinder.

Lenticel. A round, oval, or lens-shaped opening on the exterior surface of the bark.

Leucoplast (white molded). A minute colorless body within a cell. When exposed to light, leucoplasts may develop into chloroplasts.

Liana. A climbing plant.

Ligule (a small tongue). In grasses a thin appendage at the junction of leaf blade and sheath.

Medullary. Relating to the pith; medullary rays are the pith rays which radiate to the bark between the fibrovascular bundles.

Megasporangium (large spore vessel). The sporangium that produces the megaspores.

Megaspore (great or large spore). The larger one of the two kinds of asexual spores produced by certain pteridophytes and all spermatophytes.

Megasporophyll (large spore leaf). The leaf upon which the megasporangium develops.

Meristem (dividing tissue). Tissues with the cells all nearly alike and still capable of subdividing.

Mesophyll (middle leaf). The green or soft tissue of the inner part of the leaf.

Mesophytes (middle plants). Normal land plants such as grow in an average soil and under a moderate climate.

Metabolism. Chemical transformations of matter carried on by plants in the production and utilization of their food supply, and disposition of waste products.

Micropyle (small gate). The opening left by the integuments of the ovule, and which leads to the nucellus.

Microsporangium (small spore vessel). The sporangium that produces the microspore.

Microspore (small spore). The smaller spore of the two kinds produced by certain pteridophytes and all spermatophytes.

Microsporophyll (small spore leaf). The leaf upon which the microsporangium is borne.

Midrib. The central or main rib of a leaf or thallus.

Monœcious (one household). Applied to those plants upon one of which both kinds of gametes are borne. Strictly speaking, the term applies only to the gametophyte stage of plants. A monœcious seed plant bears both staminate and pistillate flowers.

Monopodial (having one foot). Said of a stem consisting of a single and continuous axis (footstalk).

Mother cell. A cell that produces new cells (usually) by internal division.

Mutualism. A symbiotic relationship in which the organisms are mutually helpful.

Mycelium (fungous growth). The filamentous vegetative growth of fungi, composed of hyphæ.

Naked. Wanting some usual covering.

Nascent. Developing or growing.

Nastic movements. Movements produced by all-round stimuli, as heat. The opening and closing of the flowers of crocuses and tulips are thermonastic movements.

Nectary. The structure in which nectar is secreted.

Nerve. A simple vein or rib.

Node (a joint). That part of a stem which normally bears leaves.

Nucellus (a little kernel). The mass of the ovule within the integuments.

Nucleolus (diminutive of nucleus). The sharply defined rounded part often seen in the nucleus.

Nucleus (a kernel). The usually roundish mass found in the protoplasm of most active cells, and differing from the rest of the protoplasm in its greater density.

Oögonium; pl. **oögonia.** The female reproductive organ of thallophytes.

Oösphere (egg sphere). The egg cell; the mass of protoplasm prepared for fertilization.

Oöspore (egg spore). The egg cell after fertilization.

Open bundle. A fibrovascular bundle which contains cambium.

Operculum (a cover or lid); pl. **opercula.** In mosses the terminal lid of the capsule, just beneath the calyptra.

Osmosis. The interchange of liquids through a membrane.

Ovary (egg-keeper). That part of the carpel in which the ovules are formed.

Ovule (an egg). The body which becomes a seed after fertilization and maturation; formerly thought to be an egg.

Palet (chaff). In grasses, the inner bract of the flower.

Palisade cells. The elongated parenchyma cells of a leaf, which stand at right angles to its surface and are often confined to the upper part of the leaf.

Palmate (pertaining to the hand). Radiating like the fingers; said of the veins or divisions of some leaves.

Panicle (a tuft). A loose and irregularly branching flower cluster, as in many grasses.

Pappus (down). The modified calyx of the composites.

Paraphysis (accompanying organs); pl. **paraphyses.** Sterile bodies, usually hairs, which are found mingled with the reproductive organs of various lower plants.

Parasite. An organism that obtains its food from the living tissues or the secretions of other organisms.

Parenchyma. Ordinary or typical cellular tissue, i.e. of thin-walled cells nearly equal in all their dimensions.

Parthenogenesis. The formation, without fertilization, of a spore which is functionally the same as a sexual spore. In general it means that the female gamete becomes a spore directly, and may grow without fertilization.

Pedicel (a little foot). The stalk upon which a structure is borne.

Peduncle (a little foot). The flower stalk.

Pentacyclic (five cycles). Applied to flowers whose four kinds of floral organs are in five cycles.

Perianth (around the flower). The floral envelopes or leaves of a flower, taken collectively; and an analogous envelope of the sporogonium of certain liverworts.

Periblem (a cloak). A name given to that part of the meristem at the growing point of the plant axis, which lies just beneath the epidermis and develops into the cortex.

Pericambium (surrounding growing tissue). In roots, the external layer of the fibrovascular cylinder.

Pericarp (around the fruit). The wall of the ovary, developed into a part of the fruit.

Perigynous (around the ovary). Applied to those flowers whose stamens and perianth arise from around the wall of the ovary.

Peristome (around the mouth). In mosses, usually bristle-like or tooth-like structures surrounding the orifice of the capsule.

Petal (a leaf). A corolla leaf.

Petiole (a little foot). The stalk of a leaf.

Phanerogamia (evident marriage). A primary division (the highest) of plants, named, from their mode of reproduction, the seed-producing plants. Phanerogam is the English equivalent.

Phloëm (the inner bark). The bark or bast portion of a fibrovascular bundle.

Photosynthesis (light construction). The name applied to the process by which chloroplasts under the influence of sunlight manufacture such carbohydrates as sugar and starch from water and carbon dioxide.

Phycocyanin (seaweed blue). A bluish coloring matter found within certain algæ.

Phyllotaxy. Leaf arrangement.

Pinna (a feather); pl. **pinnæ.** One of the primary divisions of a pinnate leaf, as in ferns.

Pinnate. Having the veins or the divisions of the leaf arranged in rows on each side of the midrib, as in black locust (*Robinia*).

Pinnule (a little feather). One of the divisions of a pinna.

Pistil (a pestle). A simple or compound carpel in spermatophytes.

Placenta; pl. **placentæ.** That portion of the ovary which bears the ovules.

Plerome (that which fills). A name given to that part of the meristem, near the growing points of the plant axis, which forms a central shaft or cylinder and develops into the axial tissues.

Plumule (a little feather). The terminal bud of the embryo above the cotyledons.

Pod. A dry, several-seeded, dehiscent fruit.

Pollen. The spores developed in the anther.

Pollen tube. The structure that develops from the wall of the microspore of spermatophytes and carries male cells to the egg.

Pollination. The transfer of pollen to the stigma.

Polypetalous (many petals). Applied to flowers that have their petals free from one another.

Prosenchyma. Tissue composed of elongated cells, with tapering ends which overlap.

Prothallium (a forerunning shoot); pl. **prothallia.** The small, usually short-lived plant which develops from the spore and bears the sex organs.

Protonema (that which is first sent out); pl. **protonemata.** In mosses, the filamentous growth which is produced by the spores, and from which the leafy moss plant is developed.

Protoplasm (that which is first formed). The living matter of cells.

Pubescent. Downy, with fine hairs.

Pyrenoid (kernel formed). Minute colorless bodies embedded in the chlorophyll structures of some lower plants.

Receptacle. That portion of an axis or pedicel (usually broadened) which forms a common support for a cluster of organs, either sex organs or sporophylls.

Respiration. The series of processes by which plants obtain energy through breaking down of protoplasm or food. Usually oxygen is used and carbon dioxide is formed as a result of the process.

Reticulated (net-like). Having a net-like appearance.

Rhizoid. Root-like; a name applied to the root-like hairs found in bryophytes and pteridophytes.

Rhizome. See *Rootstock.*

Rootstock. A horizontal, more or less thickened, root-like stem, either on the ground or underground.

Saprophyte. An organism that obtains its food from dead or decaying organisms.

Scalariform (ladder form). A name applied to ducts with piths horizontally elongated, and so placed that the intervening thickening ridges appear like the rounds of a ladder.

Scale (a flight of steps). Any thin scarious body, as a degenerated leaf, or flat hair.

Sclerenchyma. A tissue composed of cells that are thick-walled, often extremely so.

Seed. The matured ovule.

Sepal. A calyx leaf.

Seta; pl. **setæ.** A bristle, or bristle-shaped body; in mosses, the stalk of the capsule.

Sexual spore. One formed by the union of cells.

Sheath. A thin enveloping part, as of a filament, leaf, or resin duct.

Sieve cells. Cells belonging to the phloëm, and characterized by the presence of perforated plates in the wall.

Sorus (a heap); pl. **sori.** In ferns, the groups of sporangia, constituting the so-called "fruit dots"; in parasitic fungi, well-defined groups of spores, breaking through the epidermis of the host.

Sperm, or **Spermatozoid** (animal-like sperm). The male gamete.

Spermatophytes (seed plants). The highest great group of plants, of which a characteristic structure is the seed.

Spike. A flower cluster, having its flowers sessile on an elongated axis.

Spikelet (diminutive of spike). A secondary spike; in grasses, the ultimate flower cluster, consisting of one or more flowers subtended by a common pair of glumes.

Sporangium (spore vessel); pl. **sporangia.** The spore-producing structure.

Spore (seed). Originally used as the analogue of seed in flowerless plants; now applied to any one-celled or few-celled body which is separated from the parent for the purpose of reproduction, whether sexually or asexually produced; the different methods of its production are indicated by suitable prefixes.

Sporogonium (spore offspring); pl. **sporogonia.** The whole structure of the spore-bearing stage of bryophytes.

Sporophyll. A leaf that bears sporangia.

Sporophyte (spore plant). The asexual or spore-producing stage of an alternating plant.

Stamen. The microsporophyll in spermatophytes.

Stigma. That portion of the surface of a pistil (without epidermis) which receives the pollen.

Stigmatic. Relating to the stigma, or stigma-like.

Stoma (a mouth); pl. **stomata.** Epidermal structures which serve for facilitating gaseous interchanges with the external air, and for transpiration of moisture. They are often incorrectly called "breathing pores."

Strobilus. A cone-like cluster of sporophylls.

Style. The usually attenuated portion of the pistil which bears the stigma.

Succulent. Thick and fleshy.

Suspensor. A chain of cells which develops early from the oöspore, and serves to push the embryo cell deep within the embryo sac.

Symbiont. One of the organisms that has entered into a symbiotic relationship.

Symbiosis (living together). Applied to a condition in which two or more organisms are living in an intimate relationship.

Sympetalous. Having the petals apparently all united, as if grown together by their edges.

Syncarpous (carpels united). Applied to those conditions in which the carpels have united into a compound pistil.

Synergids (helpers). The two nucleated bodies which accompany the oösphere in the embryo sac, and together with it form the egg apparatus.

Testa (a shell). The outer seed coat.

Tetracyclic (four cycles). Applied to those flowers in which there are four cycles of floral organs.

Tetradynamous (four strong). Said of a stamen cluster in which there are four long and two shorter stamens.

Thalloid. Thallus-like.

Thallus (a young shoot). The body of lower plants, which exhibits no differentiation of stem, leaf, and root.

Tissue. A texture built up of mutually dependent cells of similar origin and character, as the cambium layer.

Tracheid. A long, slender cell, with closed ends and its walls thickened after the cell has attained its full size, as in the pitted cells of coniferous wood.

Transpiration. The loss of water derived from the interior of the plant body in the form of vapor. The term is not generally used with reference to plants of low organization.

Trichome (a hair). A general name for a slender outgrowth from the epidermis, usually arising from a single cell.

Turgidity. The normal swollen condition of active cells which results from the distension brought about by absorption of water.

Unisexual. Having only male or only female reproductive organs.

Vein. One of the fibrovascular bundles of leaves or of any flat organ of plants.

Venation. The mode of vein distribution.

Xerophyte. A plant capable of thriving under conditions of strongest transpiration and with scanty water supply.

Xylem (wood). The wood (inner) portion of the fibrovascular bundle.

Zoöspore (animal spore). A motile asexual spore.

Zygomorphic. Said of a flower which can be bisected by only one plane into similar halves, bilaterally symmetrical.

Zygospore (yoke spore). The spore formed by conjugation of similar gametes.

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